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USER INSTRUCTIONS FOR THE EPIC-3 CODE(U) HONEYWELL INC  
BROOKLYN PARK MN DEFENSE SYSTEMS DIV  
G R JOHNSON ET AL MAY 87 7-86-6 AFATL-TR-87-10

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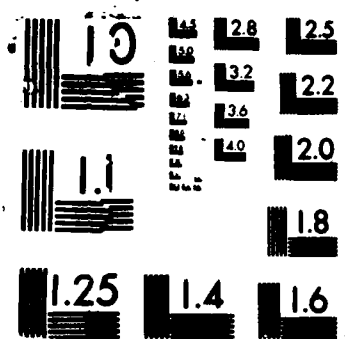
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# **User Instructions for the EPIC-3 Code**

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**G R Johnson**  
**R A Stryk**

**HONEYWELL INCORPORATED**  
**DEFENSE SYSTEMS DIVISION**  
**7225 NORTHLAND DRIVE**  
**BROOKLYN PARK, MINNESOTA 55428**

**MAY 1987**

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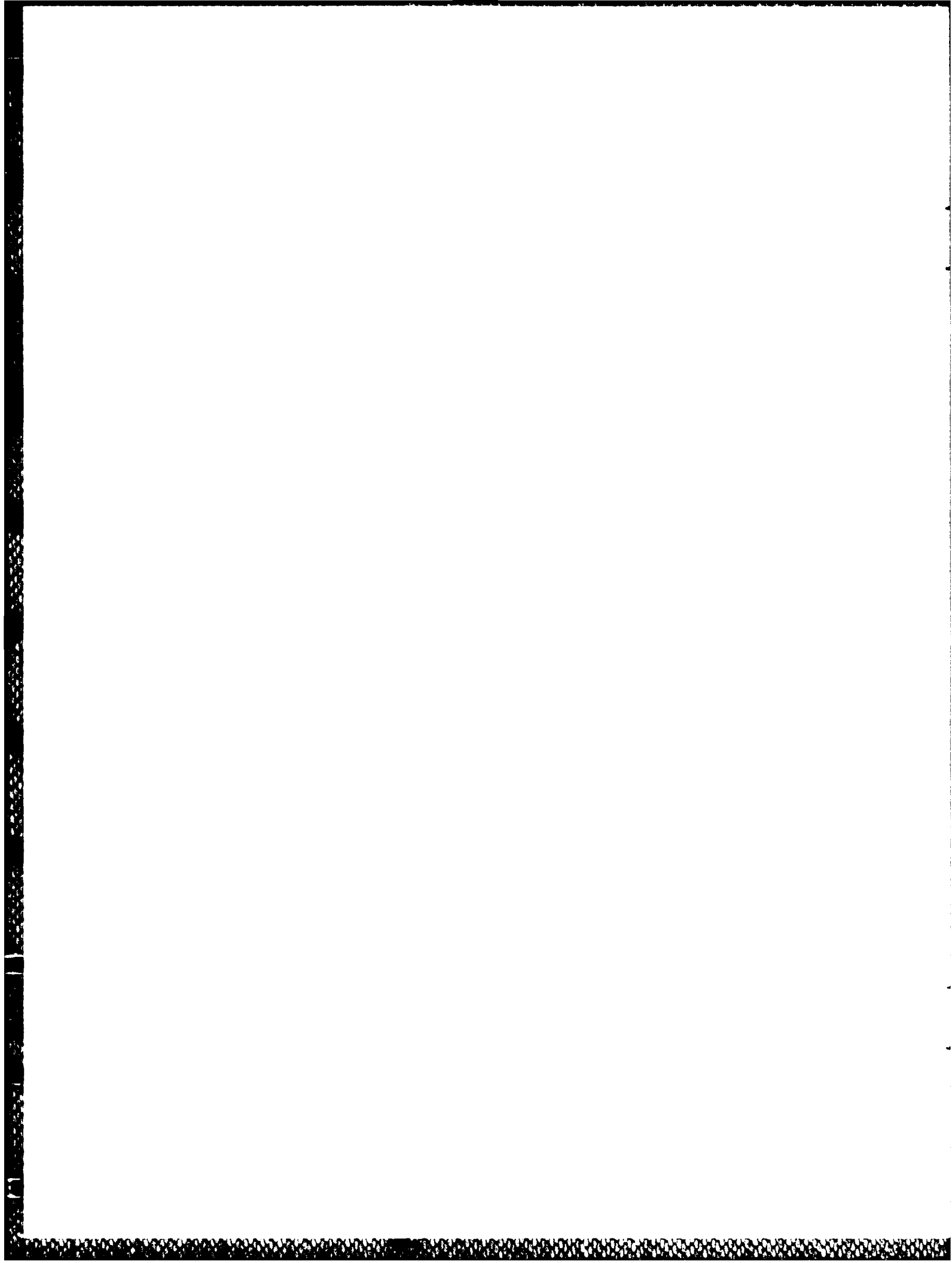


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## **SECTION I INTRODUCTION**

This report provides user instructions for the 1987 version of the three-dimensional EPIC-3 code.

The first documented version of the EPIC-3 code was developed for the Ballistic Research Laboratory (BRL) in 1977 (Reference 1), the second version was developed for the Air Force Armament Laboratory in 1978 (Reference 2), and the third version was developed for the BRL in 1980.

The 1987 version, described in this report, incorporates a NABOR node option for variable nodal connectivity. Other new features are improved material models and a data library, which are consistent with the 1986 version of the EPIC-2 code (Reference 3); eroding interfaces for projectile penetration into thick targets; and a target add option. Numerous other changes have also been incorporated since 1980.

One of the distinguishing features of the EPIC-3 code is that it is primarily based on a tetrahedral element formulation. This allows problems with severe distortions to be run without rezoning. This is a very desirable feature for many intense impulsive loading problems involving high velocity impact or explosive detonation.

The 1987 version of the EPIC-3 code, as well as the user instructions in this report, have been made as similar as possible to the corresponding 1986 version of the EPIC-2 code (Reference 3).

## SECTION II

### USER INSTRUCTIONS

This section provides user instructions for the EPIC-3 code. The code consists of a Preprocessor, Main Routine, and Postprocessor for state and time plots. The formulation is not provided here; however, most of the equations are identical to those of Reference 2. Some comments concerning the formulation of the current version of the code follow:

- The material strength models for solids and crushable materials are given in References 4 and 5.
- The fracture model for solids is given in Reference 6.
- The average pressure formulation is given in References 7 and 8.
- The sliding interface formulation is given in References 9 and 10.
- The eroding interface formulation is given in Reference 8.
- Examples of anisotropic computations, performed with the 1980 version of the EPIC-3 code, are given in Reference 7.
- The three-dimensional NABOR node formulation will appear in the final report for this contract. The NABOR formulation for plane strain is given in Reference 11.
- A characteristic of tetrahedral elements is that they sometimes produce a pressure field that oscillates spatially. This can cause inaccuracies for cases where the material strength or fracture is dependent on the pressure in the element. This is overcome by computing a nodal pressure which is the average of the element pressures for all elements that contain a specified node. The nodal pressures do not oscillate spatially but rather form a smooth pressure field. A smoothed element pressure is then defined as the average of the four associated nodal pressures. This smoothed pressure is used for the strength and fracture models, which are pressure dependent.

A description of input data for the EPIC-3 code is given in Figures 1 through 20.

DESCRIPTION CARD (A80)														*	
DESCRIPTION OF PROBLEM															
MISCELLANEOUS CARD (1415)														*	
CASE	PRINT	SAVE	NSLID	XYZRIG	SPLIT	N1R	NNR	N1L	NOR	NIR	NPL	UNIT	NRST		
MATERIAL DATA CARDS - DESCRIPTION FOLLOWS														*	
BLANK CARD 1														ENDS MATERIAL DATA	
PROJECTILE SCALE / SHIFT / ROTATE CARD (7F10.0)														*	
XSCALE	YSCALE	ZSCALE	XSHIFT	ZSHIFT	ROTATE	SLANT									
NODE DATA CARDS FOR PROJECTILE - DESCRIPTION FOLLOWS														*	
BLANK CARD 2														ENDS PROJECTILE NODE DATA	
TARGET SCALE / SHIFT / ROTATE CARD (7F10.0)														*	
XSCALE	YSCALE	ZSCALE	XSHIFT	ZSHIFT	ROTATE	SLANT									
NODE DATA CARDS FOR TARGET - DESCRIPTION FOLLOWS														*	
BLANK CARD 3														ENDS TARGET NODE DATA	
ELEMENT DATA CARDS FOR PROJECTILE - DESCRIPTION FOLLOWS														*	
BLANK CARD 4														ENDS PROJECTILE ELEMENT DATA	
ELEMENT DATA CARDS FOR TARGET - DESCRIPTION FOLLOWS														*	
BLANK CARD 5														ENDS TARGET ELEMENT DATA	
SLIDING SURFACE IDENTIFICATION CARDS - AS REQUIRED (10I5, 3F10.0)															
MGEOM	SEEK	IT	M1	S1	SN	NSN	NSG	ISR	NAB	FRICT	REFVEL	ERODE			
MASTER DEFINITION CARD FOR PLATE GEOMETRY (MGEOM = 1) (9I5)															
NML	NMW	IDL	IDW	IDIA	NBOT	NLAST	MGNXT	M1NXT							
MASTER DEFINITION CARD FOR NOSE-ROD GEOMETRY (MGEOM = 2) (3I5, 20X, 2I5)															
NOR	NIR	NPL					MGNXT	M1NXT							
MASTER DEFINITION CARD FOR DISK GEOMETRY (MGEOM = 3) (2I5, 15X, 4I5)															
NRING	MCODE				NBOT	NLAST	MGNXT	M1NXT							
MASTER DEFINITION CARD FOR CYLINDER GEOMETRY (MGEOM = 4) (4I5, 15X, 2I5)															
NRING	NPL	IDL	MCODE				MGNXT	M1NXT							
MASTER DEFINITION CARD FOR GENERAL GEOMETRY (MGEOM = 5) (4I5)															
NBOT	NLAST	MGNXT	M1NXT												
INDIVIDUAL MASTER SURFACE CARD(S) FOR MGEOM = 5 (7I5)															
NCOMP	M1	M2	M3	M4	M5	INC									
SLAVE NODE LIMITS CARD FOR NSN=0 (6F10.0, I5)															
XMAX	XMIN	YMAX	YMIN	ZMAX	ZMIN	NBOX									
NSG GROUPED SLAVE NODE CARD(S) FOR NSG>0 (3I5)															
STG	SG	INC													
INDIVIDUAL SLAVE NODE CARD(S) FOR NSN>0 AND NSG = 0 (16I5)															
S1	S2												SN		

Figure 1a. Preprocessor Input Data

F1	F2								FN					
----	----	--	--	--	--	--	--	--	----	--	--	--	--	--

F1G	FNG	INC	
-----	-----	-----	--

XDET	YDET	ZDET	TBURN	
------	------	------	-------	--

PXDOT	PYDOT	PZDOT	TXDOT	TYDOT	TZDOT	DT1	
-------	-------	-------	-------	-------	-------	-----	--

\* INDICATES REQUIRED CARDS - ALL OTHERS OPTIONAL

**Figure 1b. Preprocessor Input Data**

MATERIAL CARDS FOR SOLIDS FROM LIBRARY (415, 2F5.0)

MATL	0	IDAM	IFAIL	DFRAC	EFAIL			
------	---	------	-------	-------	-------	--	--	--

5 MATERIAL CARDS FOR SOLIDS INPUT DATA: (415, 5X, F5.0, A48/4(8F10.0))

MATL	1	IDAM	IFAIL		EFAIL	MATERIAL DESCRIPTION		
------	---	------	-------	--	-------	----------------------	--	--

DENSITY	SPH HEAT	CONDUCT	ALPHA	TEMP1	TROOM	TMELT	X1
---------	----------	---------	-------	-------	-------	-------	----

SHEAR MOD	C1	C2	N	C3	M	C4	SMAX
-----------	----	----	---	----	---	----	------

K1	K2	K3	$\Gamma$	CL	CQ	PMIN	CH
----	----	----	----------	----	----	------	----

D1	D2	D3	D4	D5	SPALL	EFMIN	X2
----	----	----	----	----	-------	-------	----

MATERIAL CARDS FOR EXPLOSIVES FROM LIBRARY (215)

MATL	0							
------	---	--	--	--	--	--	--	--

3 MATERIAL CARDS FOR EXPLOSIVES INPUT DATA: (215, 20X, A48/6F10.0/7F10.0)

MATL	2				MATERIAL DESCRIPTION			
------	---	--	--	--	----------------------	--	--	--

DENSITY	ENERGY	DET VEL	CL	CQ	CH			
---------	--------	---------	----	----	----	--	--	--

C1	C2	C3	C4	C5	X1	X2		
----	----	----	----	----	----	----	--	--

MATERIAL CARDS FOR CRUSHABLE SOLIDS FROM LIBRARY (215, 15X, F5.0)

MATL	0				EFAIL			
------	---	--	--	--	-------	--	--	--

4 MATERIAL CARDS FOR CRUSHABLE SOLIDS INPUT DATA (215, 15X, F5.0, A48/3F10.0/2(8F10.0))

MATL	3				EFAIL	MATERIAL DESCRIPTION		
------	---	--	--	--	-------	----------------------	--	--

DENSITY	SPH HEAT	TEMP1						
---------	----------	-------	--	--	--	--	--	--

SHEAR MOD	C1	C4	SMAX	CL	CQ	PMIN	CH
-----------	----	----	------	----	----	------	----

PCRUSH	UCRUSH	K1	K2	K3	KLOCK	ULOCK	X1
--------	--------	----	----	----	-------	-------	----

7 MATERIALS CARDS FOR ANISOTROPIC SOLIDS INPUT DATA (415, 5X, F5.0, A48/3F10.0/8F10.0/2(6F10.0)/2(8F10.0))

MATL	4	IDAM	IFAIL		EFAIL	MATERIAL DESCRIPTION		
------	---	------	-------	--	-------	----------------------	--	--

$\theta_1$	$\theta_2$	$\theta_3$						
------------	------------	------------	--	--	--	--	--	--

DENSITY	SPH HEAT	TEMP1	TROOM	TMELT	$V_{xy}$	$V_{yz}$	$V_{zx}$
---------	----------	-------	-------	-------	----------	----------	----------

$E_x$	$E_y$	$E_z$	$G_{xy}$	$G_{yz}$	$G_{zx}$			
-------	-------	-------	----------	----------	----------	--	--	--

X-YIELD	Y-YIELD	Z-YIELD	XY-YIELD	YZ-YIELD	ZX-YIELD			
---------	---------	---------	----------	----------	----------	--	--	--

K1	K2	K3	$\Gamma$	CL	CQ	PMIN	CH
----	----	----	----------	----	----	------	----

D1	D2	D3	D4	D5	SPALL	EFMIN	X1
----	----	----	----	----	-------	-------	----

Figure 2. Material Input Data

LINE OF NODES DESCRIPTION CARD (215, 8F10.0, F7.0, 311)

1	NODE	X1	Y1	Z1	XN	YN	ZN	EXPAND	
---	------	----	----	----	----	----	----	--------	--

ROD NODE IDENTIFICATION CARD (15)

2									
---	--	--	--	--	--	--	--	--	--

ROD NODE DESCRIPTION CARD (415, 3F10.0)

NOR	NIR	NPLN	IRAD	ZTOP	ZBOT	EXPAND			
-----	-----	------	------	------	------	--------	--	--	--

ROD NODE RADII CARD FOR IRAD=0 (4F10.0)

ROTOP	RITOP	ROBOT	RIBOT						
-------	-------	-------	-------	--	--	--	--	--	--

ROD NODE TOP RADII CARD(S) FOR IRAD=1 (8F10.0)

RT(NIR)								RT(NOR)	
---------	--	--	--	--	--	--	--	---------	--

ROD NODE BOTTOM RADII CARD(S) FOR IRAD=1 (8F10.0)

RB(NIR)								RB(NOR)	
---------	--	--	--	--	--	--	--	---------	--

ROD NODE TOP SURFACE CARD FOR IRAD=1 (8F10.0)

ZT(NIR)								ZT(NOR)	
---------	--	--	--	--	--	--	--	---------	--

ROD NODE BOTTOM SURFACE CARD FOR IRAD=1 (8F10.0)

ZB(NIR)								ZB(NOR)	
---------	--	--	--	--	--	--	--	---------	--

NOTE: IF NIR=0 BEGIN RADII AND SURFACE CARDS WITH RT(1) AND RB(1)

NOSE NODE IDENTIFICATION CARD (15)

3									
---	--	--	--	--	--	--	--	--	--

NOSE NODE DESCRIPTION CARD (415, 4F10.0)

NOR	NIR	INOSE	IRAD	ROTOP	RITOP	ZTOP	ZMIN		
-----	-----	-------	------	-------	-------	------	------	--	--

NOSE NODE TOP RADII CARD(S) FOR IRAD = 1 (8F10.0)

RT(NIR)								RT(NOR)	
---------	--	--	--	--	--	--	--	---------	--

NOSE NODE ZMIN CARD(S) FOR IRAD = 1 (8F10.0)

ZM(NIR)								ZM(NOR)	
---------	--	--	--	--	--	--	--	---------	--

NOTE: IF NIR = 0 BEGIN TOP RADII AND ZMIN CARDS WITH RT(1) AND ZM(1)

FLAT PLATE NODE IDENTIFICATION CARD (215)

4	TYPE								
---	------	--	--	--	--	--	--	--	--

FLAT PLATE NODE DESCRIPTION CARD FOR TYPE = 1 (815, 5F10.0)

NX	NY	NZ	NXEND	NYEND	IV	X-EXPAND	X-PART	Y-EXPAND	Y-PART	Z-EXPAND
----	----	----	-------	-------	----	----------	--------	----------	--------	----------

FLAT PLATE NODE DESCRIPTION CARD FOR TYPE = 2 (815, 5F10.0)

NX	NY	NZ	NXEND	NZEND	IV	X-EXPAND	X-PART	Z-EXPAND	Z-PART	Y-EXPAND
----	----	----	-------	-------	----	----------	--------	----------	--------	----------

FLAT PLATE NODE SIZE CARD (8F10.0)

X1	Y1	Z1	XN	YN	ZN				
----	----	----	----	----	----	--	--	--	--

Figure 3a. Node Input Data



SPHERE NODE IDENTIFICATION CARD (I5)

5										
---	--	--	--	--	--	--	--	--	--	--

SPHERE NODE DESCRIPTION CARD (2I5, 5X, I5, 3F10.0)

NOR	NIR	IRAD	RO	RI	ZCG					
-----	-----	------	----	----	-----	--	--	--	--	--

SPHERE NODE RADII CARD(S) FOR IRAD = 1 (8F10.0)

R(NIR)						R(NOR)			
--------	--	--	--	--	--	--------	--	--	--

NOTE: IF NIR = 0 BEGIN RADII CARD WITH R(1)

NABOR FILLED PLATE NODE IDENTIFICATION CARD (I5)

6										
---	--	--	--	--	--	--	--	--	--	--

NABOR FILLED PLATE NODE DESCRIPTION CARD (7I5, 5X, 3F10.0)

NNX	NNY	NNZ	MATL	NXEND	NYEND	IY	X-EXPAND	Y-EXPAND	DO
-----	-----	-----	------	-------	-------	----	----------	----------	----

NABOR FILLED PLATE SIZE CARD (5E10.0)

X1	Y1	ZTOP	XN	YN	
----	----	------	----	----	--

NABOR BRICK NODE IDENTIFICATION CARD (I5)

7										
---	--	--	--	--	--	--	--	--	--	--

NABOR BRICK NODE DESCRIPTION CARD (2I57, F10.0)

MATL	IY	DO	X1	Y1	Z1	XN	YN	ZN
------	----	----	----	----	----	----	----	----

Figure 3b. Node Input Data

SERIES OF COMPOSITE ELEMENTS DESCRIPTION CARD (1215)

1	NCOMP	MATL	N1	N2	N3	N4	N5	N6	N7	N8	INC	
---	-------	------	----	----	----	----	----	----	----	----	-----	--

ROD ELEMENT IDENTIFICATION CARD (15)

2	
---	--

ROD ELEMENT DESCRIPTION CARD (515)

NOER	NIER	NLAY	N1	MATL	
------	------	------	----	------	--

ROD ELEMENT MATERIAL CARD FOR MATL = 0 (1615)

M(NIER)												M(NOER)			
---------	--	--	--	--	--	--	--	--	--	--	--	---------	--	--	--

NOSE ELEMENT IDENTIFICATION CARD (15)

3	
---	--

NOSE ELEMENT DESCRIPTION CARD (215, 5X, 215)

NOER	NIER		N1	MATL	
------	------	--	----	------	--

NOSE ELEMENT MATERIAL CARD FOR MATL = 0 (1615)

M(NIER)												M(NOER)			
---------	--	--	--	--	--	--	--	--	--	--	--	---------	--	--	--

FLAT PLATE ELEMENT IDENTIFICATION CARD (215)

4	TYPE	
---	------	--

FLAT PLATE DESCRIPTION CARD (515)

NLX	NLY	NLZ	N1	MATL	
-----	-----	-----	----	------	--

SPHERE ELEMENT IDENTIFICATION CARD (15)

5	
---	--

SPHERE ELEMENT DESCRIPTION CARD (215, 5X, 215)

NOER	NIER		N1	MATL	
------	------	--	----	------	--

SPHERE ELEMENT MATERIAL CARD FOR MATL = 0 (1615)

M(NIER)												M(NOER)			
---------	--	--	--	--	--	--	--	--	--	--	--	---------	--	--	--

NABOR FILLED PLATE ELEMENT IDENTIFICATION CARD (15)

6	
---	--

NABOR FILLED PLATE ELEMENT DESCRIPTION CARD (715)

NNX	NNY	NNZ	MATL	NXEND	NYEND	N1	
-----	-----	-----	------	-------	-------	----	--

Figure 4. Element Input Data

DESCRIPTION CARD (A80)

DESCRIPTION OF PROBLEM									
------------------------	--	--	--	--	--	--	--	--	--

IDENTIFICATION CARD (5I5, 5X, 5F10.0)

CASE	CYCLE	IPRES	CHANG	IHRG	VFRACT	PMAX	VNREF	ARMAX	ASERR
------	-------	-------	-------	------	--------	------	-------	-------	-------

INTEGRATION TIME INCREMENT CARD (8F10.0)

DTMAX	DTMIN	SSF	TMAX	CPMAX	EMAX				
-------	-------	-----	------	-------	------	--	--	--	--

PRESSURE CARDS FOR IPRES = 2 - AS REQUIRED (8I5, F10.0)

ELE1	ELEN	ELEINC	N1	NN	NODINC	PRES				
------	------	--------	----	----	--------	------	--	--	--	--

BLANK CARD INCLUDED ONLY FOR IPRES = 2

TIME - PRESSURE CARDS FOR IPRES = 2 - AS REQUIRED (2F10.0)

PTIME	P(T)								
-------	------	--	--	--	--	--	--	--	--

BLANK CARD INCLUDED ONLY FOR IPRES = 2

CHANGE DROP CARD FOR CHANG = 1 OR 2 (F10.0, 10I5)

TDROP	MODE	PNODE	ELE	PELE	NSLID	NPLT	PLOT	NFAIL	NAB	PNAB		
-------	------	-------	-----	------	-------	------	------	-------	-----	------	--	--

DESIGNATED ELEMENT FAILURE CARD - FOR NFAIL > 0 (16I5)

EF1	EF2								EFN					
-----	-----	--	--	--	--	--	--	--	-----	--	--	--	--	--

CHANGE ADD CARD FOR CHANG = 2 OR 3 (F10.0, 11I5)

TADD	NSLID	KYZRIG	SPLIT	N1R	NNR	N1L	NOR	NIR	NPL	NRST	IPRINT		
------	-------	--------	-------	-----	-----	-----	-----	-----	-----	------	--------	--	--

TARGET SCALE / SHIFT / ROTATE CARD FOR CHANG = 2 OR 3 (7F10.0)

XSCALE	YSCALE	ZSCALE	XSHIFT	ZSHIFT	ROTATE	SLANT		
--------	--------	--------	--------	--------	--------	-------	--	--

ADDITIONAL TARGET NODE DATA FOR CHANG = 2 OR 3 - AS REQUIRED

BLANK CARD ENDS NODE DATA FOR CHANG = 2 OR 3

ADDITIONAL TARGET ELEMENT DATA FOR CHANG = 2 OR 3 - AS REQUIRED

BLANK CARD ENDS ELEMENT DATA FOR CHANG = 2 OR 3

NSLID DATA - AS REQUIRED FOR CHANG = 2 OR 3  
 NRST DATA - AS REQUIRED FOR CHANG = 2 OR 3 } SAME FORMAT AS USED IN PREPROCESSOR

TARGET VELOCITY CARD FOR CHANG = 2 OR 3 (30X, 3F10.0)

			TXDOT	TYDOT	TZDOT			
--	--	--	-------	-------	-------	--	--	--

BLANK CARD ENDS DATA FOR CHANG = 2 OR 3

Figure 5a. Main Routine Input Data

PLOT CARD (5I5, 5X, 4F10.0)

CYCLE	SYS	LOAD	NPLOT	LPLT		DT SYS	TSYS	DT NODE	TNODE	
-------	-----	------	-------	------	--	--------	------	---------	-------	--

DESIGNATED NODES CARDS - AS REQUIRED (16I5)

N1	N2										NN			
----	----	--	--	--	--	--	--	--	--	--	----	--	--	--

DESIGNATED ELEMENTS CARDS - AS REQUIRED (16I5)

E1	E2										EN			
----	----	--	--	--	--	--	--	--	--	--	----	--	--	--

DATA OUTPUT CARDS - AS REQUIRED (2F10.0, 3I5)

TIME	ECHECK	LOAD	SAVE	YPRINT	
------	--------	------	------	--------	--

BLANK CARD

Figure 5b. Main Routine Input Data

GEOMETRY PLOT CARD (E12, F10, G12, H4, E12, F04, F007)									
1	CYCLE	TIME							TITLE

AXIS

VIEW

MATL

FAIL

XMAX	XMIN	YMAX	YMIN	ZMAX	ZMIN	LMAX	LMIN	
------	------	------	------	------	------	------	------	--

XEYE	YEYE	ZEYE	XPLANE	YPLANE	ZPLANE	LHIDE	
------	------	------	--------	--------	--------	-------	--

2	CYCLE	TIME					VSCALE	TITLE
---	-------	------	--	--	--	--	--------	-------

AXES —┐  
 VIEW —┐

ARROW —┐  
 EDGE —┐

XMAX	XMIN	YMAX	YMIN	ZMAX	ZMIN	
------	------	------	------	------	------	--

XEYE	YEYE	ZEYE	XPLANE	YPLANE	ZPLANE	
------	------	------	--------	--------	--------	--

[illegible]

XMAX	XMIN	YMAX	YMIN	ZMAX	ZMIN	
------	------	------	------	------	------	--

VAR (1)	VAR (2)					VAR(NLINE)
---------	---------	--	--	--	--	------------

<u>TYPE</u>	<u>VARIABLE PLOTTED</u>
3	PRESSURE
4	VON MISES STRESS
5	EQUIVALENT PLASTIC STRAIN
6	DAMAGE
7	TEMPERATURE
8	PLASTIC WORK PER INITIAL VOLUME
9	INTERNAL ENERGY PER INITIAL VOLUME
10	LOG (10) STRAIN RATE

•

[illegible]

PMAX	PMIN	VMAX	VMIN	BMAX	BMIN	LENGTH	
------	------	------	------	------	------	--------	--

1

11

SYSTEM PLOT CARDS - AS REQUIRED (215, 5X, F5.0, 4F10.0, A20)

TYPE	AXES	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	-------	------	------	------	------	-------

INTERNAL LOADS PLOT CARDS - AS REQUIRED (315, F5.0, 4F10.0, A20)

TYPE	AXES	LAYER	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	-------	-------	------	------	------	------	-------

INDIVIDUAL NODE PLOT CARDS - AS REQUIRED (315, F5.0, 4F10.0, A20)

TYPE	AXES	NODE	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	------	-------	------	------	------	------	-------

INDIVIDUAL ELEMENT PLOT CARDS - AS REQUIRED (315, F5.0, 4F10.0, A20)

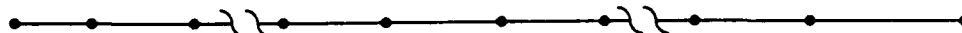
TYPE	AXES	ELE	SCALE	TMAX	TMIN	VMAX	VMIN	TITLE
------	------	-----	-------	------	------	------	------	-------

BLANK CARD

TYPE	VARIABLE PLOTTED	
1 - 4	ENERGIES: TOTAL (1), KINETIC (2), INTERNAL (3), PLASTIC WORK (4)	SYSTEM DATA
5 - 7	XYZ MAXIMUM COORDINATES	
8 - 10	XYZ MINIMUM COORDINATES	
11 - 13	XYZ CENTERS OF GRAVITY	
14 - 16	XYZ LINEAR MOMENTA	
17 - 20	XYZ VELOCITIES (17 - 19) AND NET VELOCITY (20)	
21 - 23	XYZ ANGULAR MOMENTA	INTERNAL LOADS DATA
24 - 26	XYZ ANGULAR VELOCITIES	
27 - 29	INTERNAL LOADS: AXIAL (27), SHEAR (28), BENDING (29)	
30 - 32	XYZ NODE POSITIONS	INDIVIDUAL NODE DATA
33 - 35	XYZ NODE VELOCITIES	
36 - 38	XYZ NODE ACCELERATIONS	
39	NODAL PRESSURES	INDIVIDUAL ELEMENT DATA
40	ELEMENT PRESSURES	
41 - 43	XYZ NORMAL STRESSES	
44 - 46	SHEAR STRESSES: X-Y (44), X-Z (45), Y-Z (46)	
47	VON MISES STRESS	
48	EQUIVALENT PLASTIC STRAIN	
49	TEMPERATURE	
50	INTERNAL ENERGY PER INITIAL VOLUME	
51	PLASTIC WORK PER INITIAL VOLUME	
52	DAMAGE	
53	RATIO: MEAN STRESS / VON MISES STRESS	

Figure 7. Postprocessor Input Data for Time Plots

NUMBER OF INCRE- MENTS	EXPAND																	
	.7		.8		.9		1.0		1.1		1.2		1.3		1.4		1.5	
	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$	$\frac{\Delta_1}{\Delta}$	$\frac{\Delta_2}{\Delta}$
2	1.176	.824	1.111	.889	1.053	.947	1.0	1.0	.952	1.048	.909	1.091	.870	1.130	.833	1.167	.800	1.200
3	1.370	.671	1.230	.767	1.107	.887			.906	1.097	.824	1.187	.752	1.271	.688	1.340	.632	1.421
4	1.579	.542	1.355	.644	1.163	.840			.862	1.147	.745	1.288	.647	1.420	.563	1.545	.482	1.662
5	1.803	.433	1.487	.509	1.221	.781			.819	1.199	.672	1.393	.553	1.579	.457	1.755	.379	1.919
6	2.040	.343	1.626	.373	1.281	.716			.778	1.222	.604	1.504	.470	1.746	.368	1.977	.289	2.192
7	2.280	.260	1.772	.264	1.342	.657			.738	1.307	.542	1.618	.390	1.922	.293	2.210	.218	2.487
8	2.547	.210	1.923	.203	1.405	.594			.700	1.363	.485	1.737	.335	2.104	.233	2.452	.162	2.775
9	2.814	.162	2.079	.149	1.469	.530			.663	1.421	.433	1.861	.281	2.293	.183	2.702	.120	3.080
10	3.087	.125	2.241	.101	1.535	.465			.627	1.479	.385	1.988	.235	2.408	.143	2.959	.088	3.392
12	3.651	.072	2.577	.021	1.672	.325			.561	1.601	.303	2.253	.161	2.893	.086	3.480	.047	4.031
14	4.229	.041	2.929	.011	1.815	.201			.500	1.728	.237	2.530	.109	3.315	.051	4.036	.024	4.683
16	4.816	.023	3.293	.016	1.964	.104			.445	1.859	.183	2.819	.073	3.749	.030	4.592	.012	5.341
18	5.409	.013	3.666	.003	2.118	.053			.395	1.995	.140	3.117	.046	4.191	.017	5.155	.006	6.004
20	6.003	.003	4.037	.004	2.246	.023			.349	2.102	.089	3.407	.024	4.634	.007	5.719	.002	6.668



$$\bar{\Delta} = \frac{\text{TOTAL LENGTH}}{\text{NUMBER INCREMENTS}} = \frac{L}{N}$$

$$\Delta_{i+1} = \Delta_i \cdot \text{EXPAND}$$

$$\frac{\Delta_1}{\Delta} = \frac{N(1 - \text{EXPAND})}{(1 - \text{EXPAND})^N}$$

$$\frac{\Delta_N}{\Delta} = \frac{N \left( 1 - \frac{1}{\text{EXPAND}} \right)}{\left[ 1 - \left( \frac{1}{\text{EXPAND}} \right)^N \right]}$$

**Figure 8. Nodal Spacing for Various Expansion Factors**

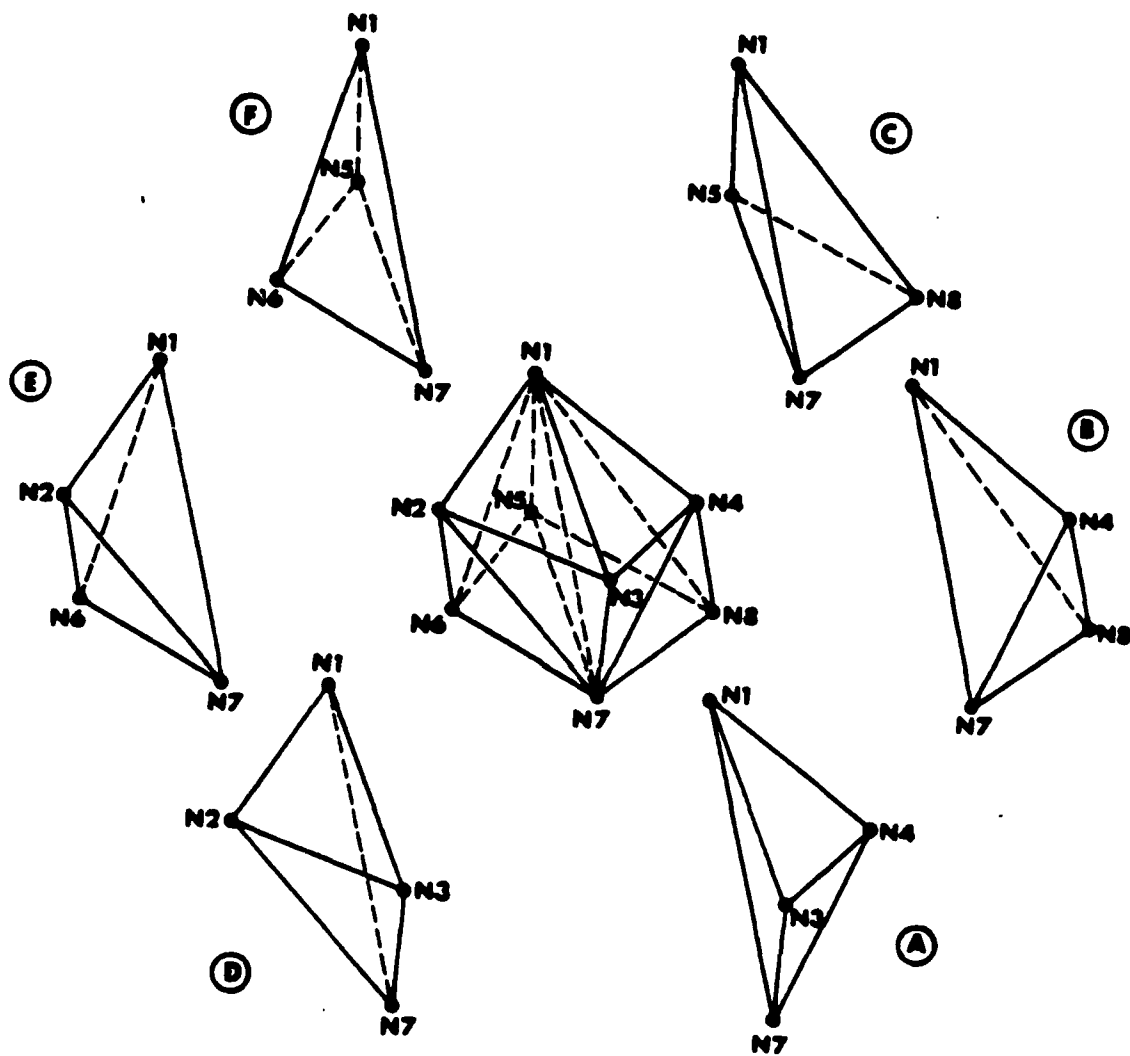


Figure 9. Arrangement of Six Tetrahedra into a Composite Brick Element



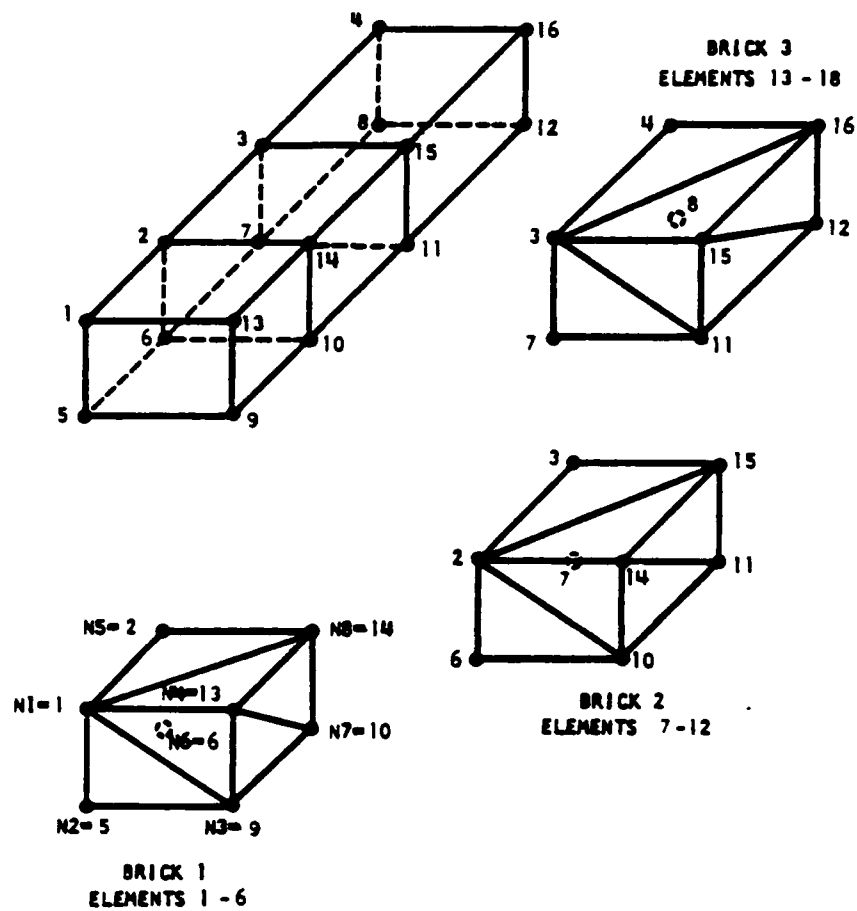


Figure 10. Node/Element Input Data Example

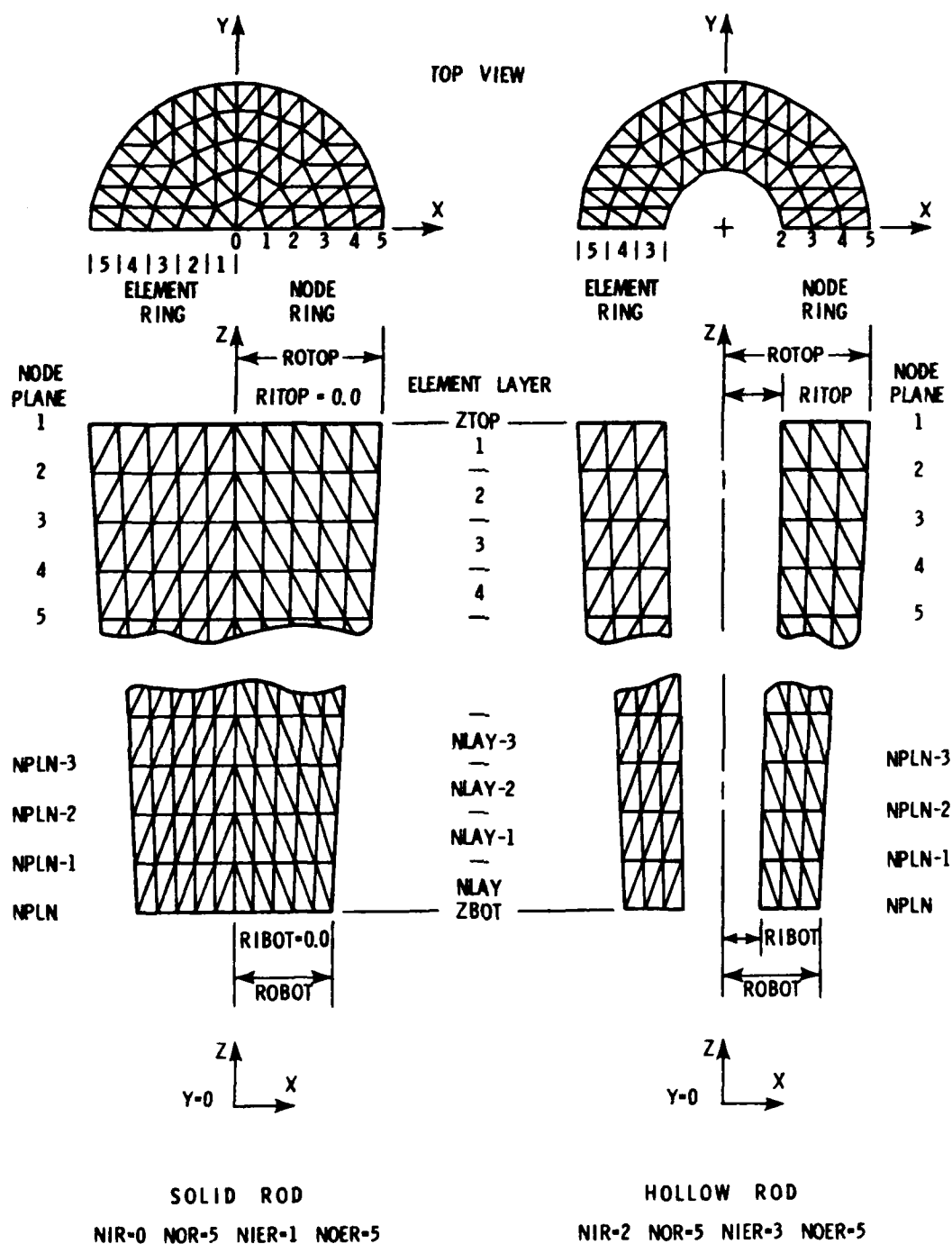


Figure 11. Rod Shape Geometry

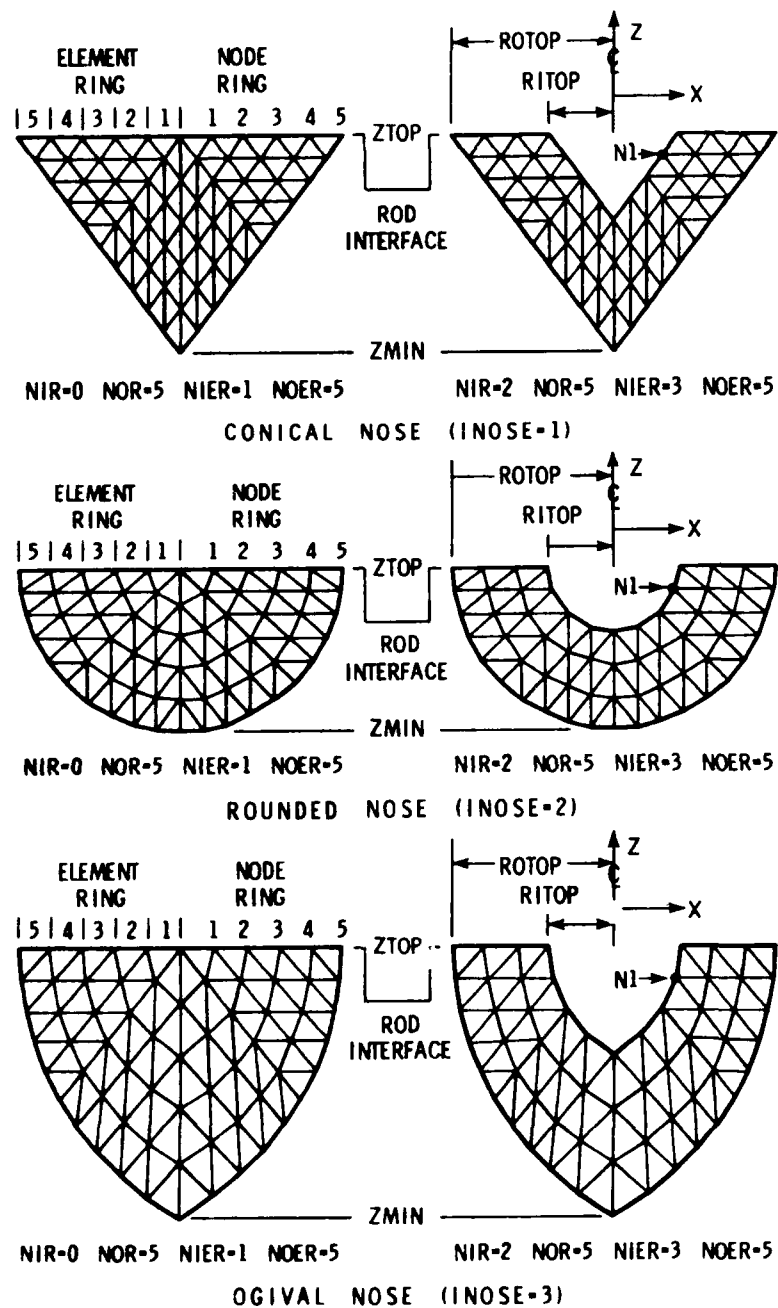
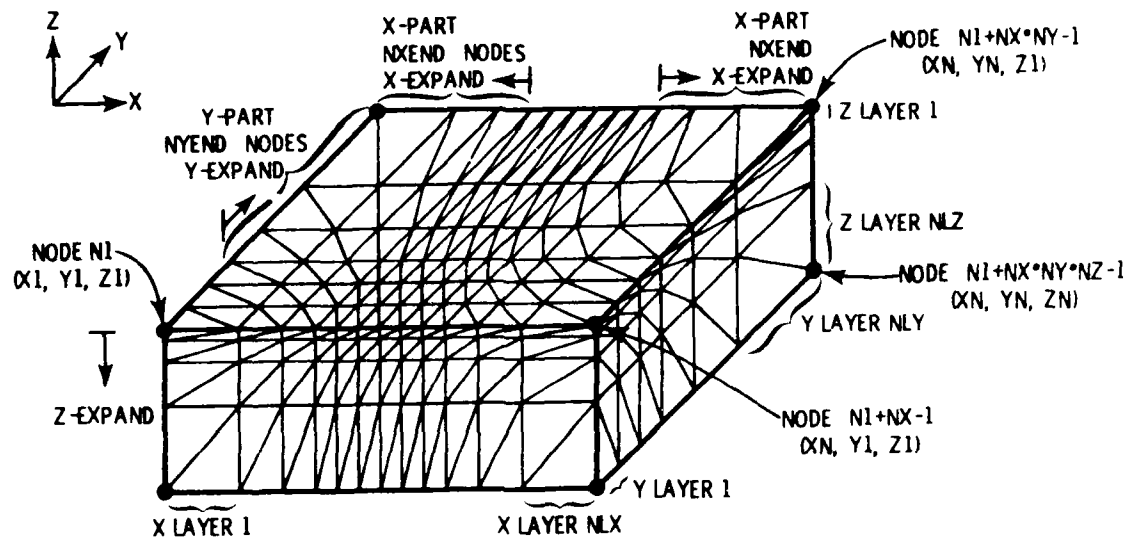


Figure 12. Nose Shape Geometry

### TYPE - 1 (HORIZONTAL LAYERS)



### TYPE - 2 (VERTICAL LAYERS)

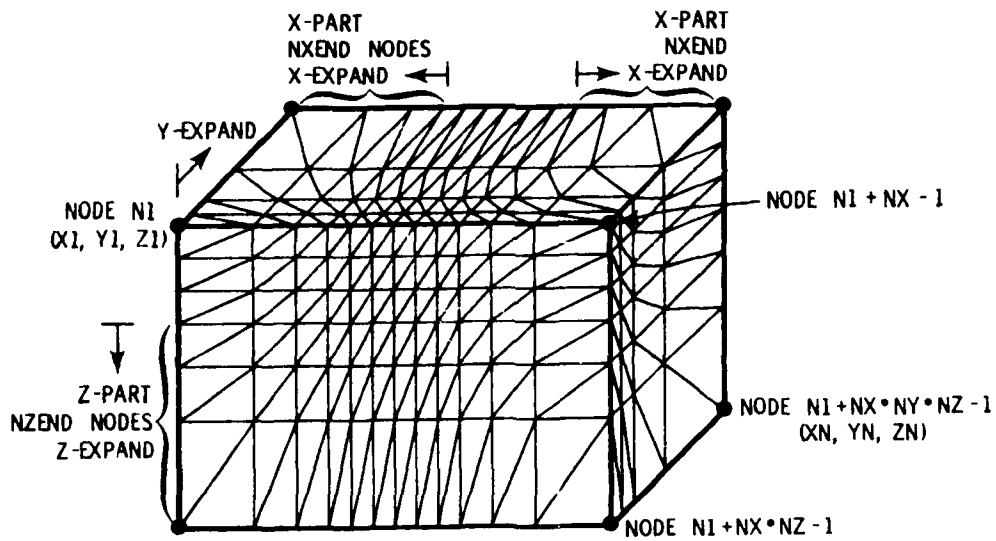


Figure 13. Flat Plate Geometry

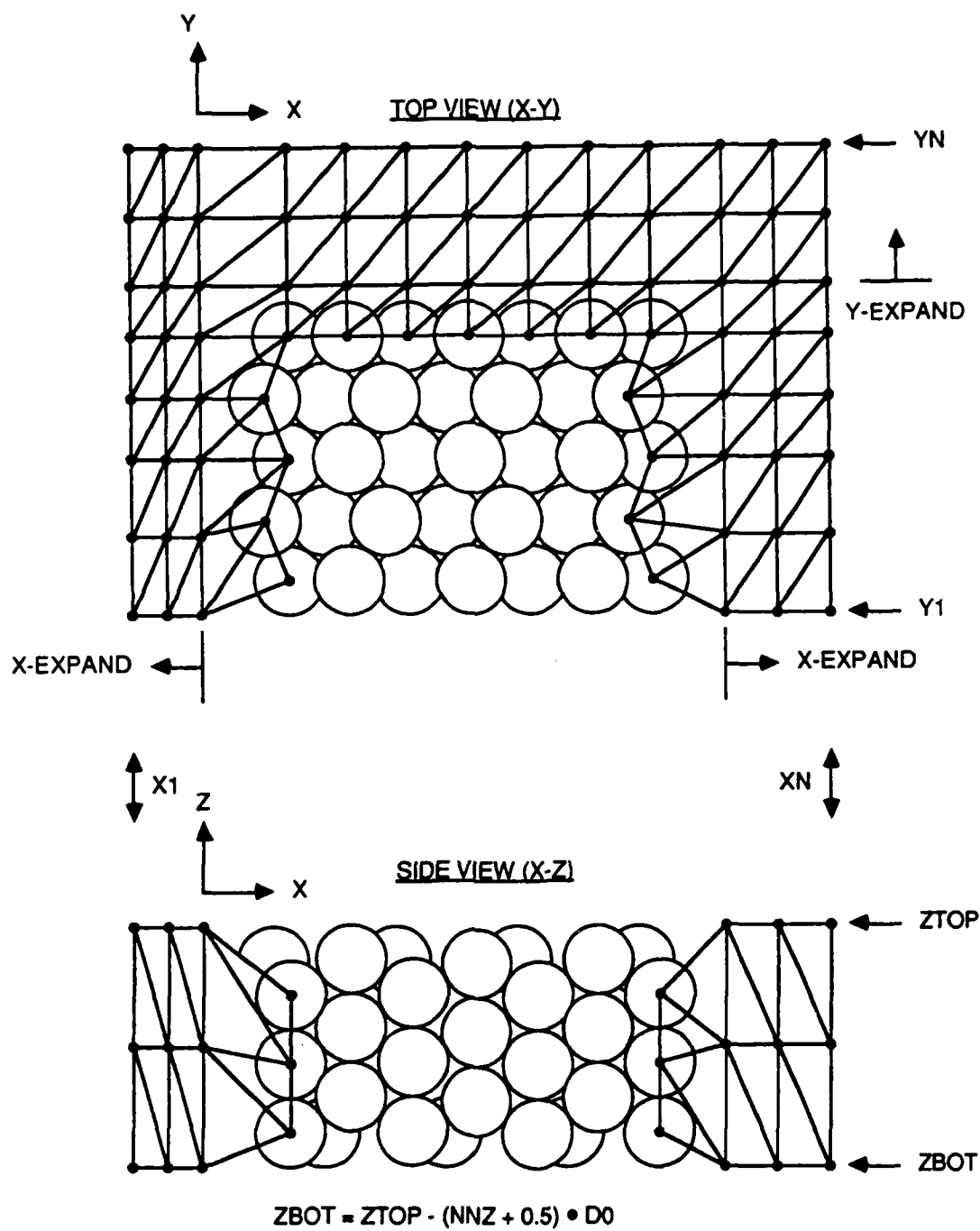


Figure 14. NABOR Filled Plate Node Geometry

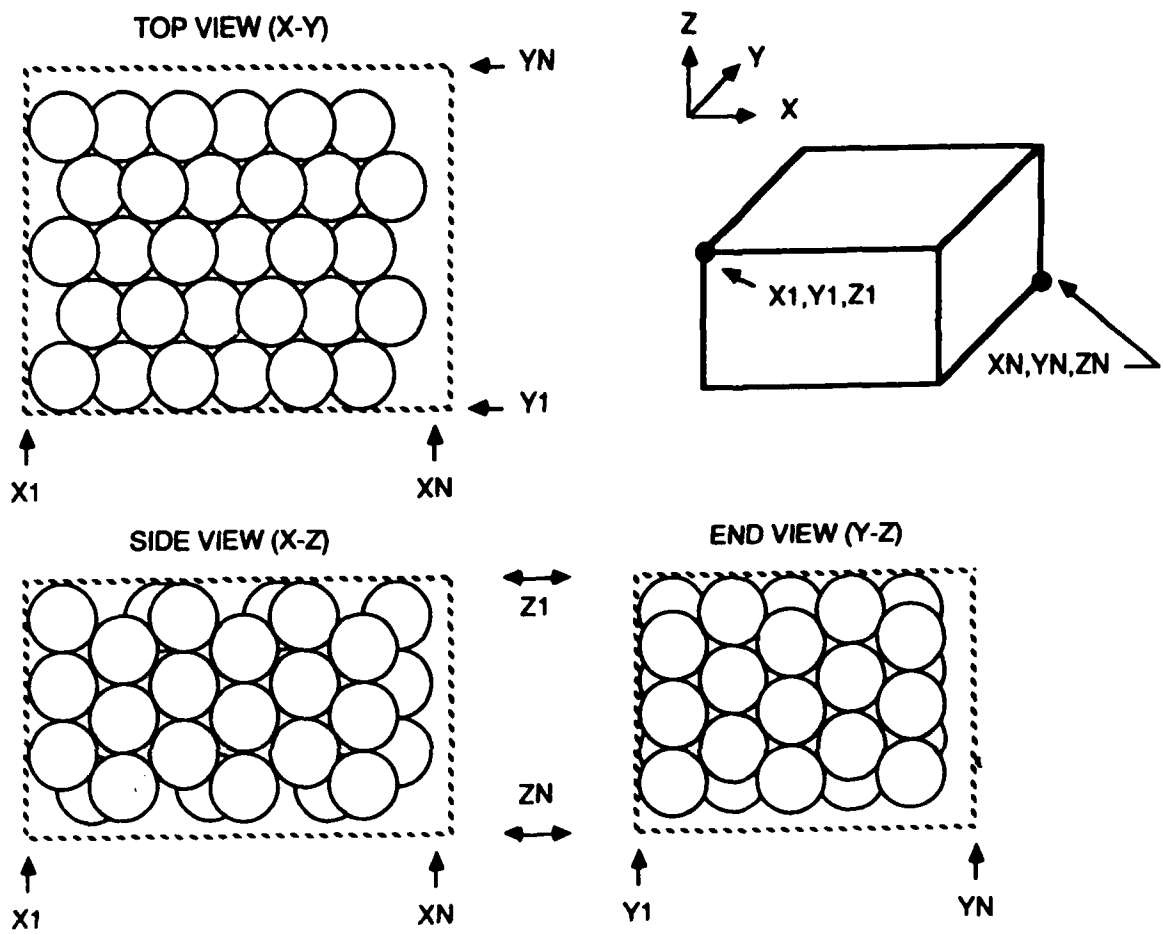


Figure 15. NABOR Node Geometry

NUMBER OF RINGS	ROD *		NOSE *		SPHERE *	
	NODES PER PLANE	ELEMENTS PER LAYER	NODES **	ELEMENTS	NODES	ELEMENTS
0	1	-	0	-	1	-
1	6	12	6	12	18	24
2	15	48	30	96	75	192
3	28	108	84	324	196	648
4	45	192	180	768	405	1536
5	66	300	330	1500	726	3000
6	91	432	546	2592	1183	5184
7	120	588	840	4116	1800	8232
8	153	768	1224	6144	2601	12288
9	190	972	1710	8748	3610	17496
10	231	1200	2310	12000	4851	24000
11	276	1452	3036	15972	6348	31944
12	325	1728	3900	20736	8125	41472
13	378	2028	4914	26364	10206	52728
14	435	2352	6090	32928	12615	65856
15	496	2700	7440	40500	15376	81000
16	561	3072	8976	49152	18513	98304

\* ONLY HALF GENERATED

\*\* DOES NOT INCLUDE NODES AT ROD INTERFACE

Figure 16. Summary of Nodes and Elements in Various Shapes

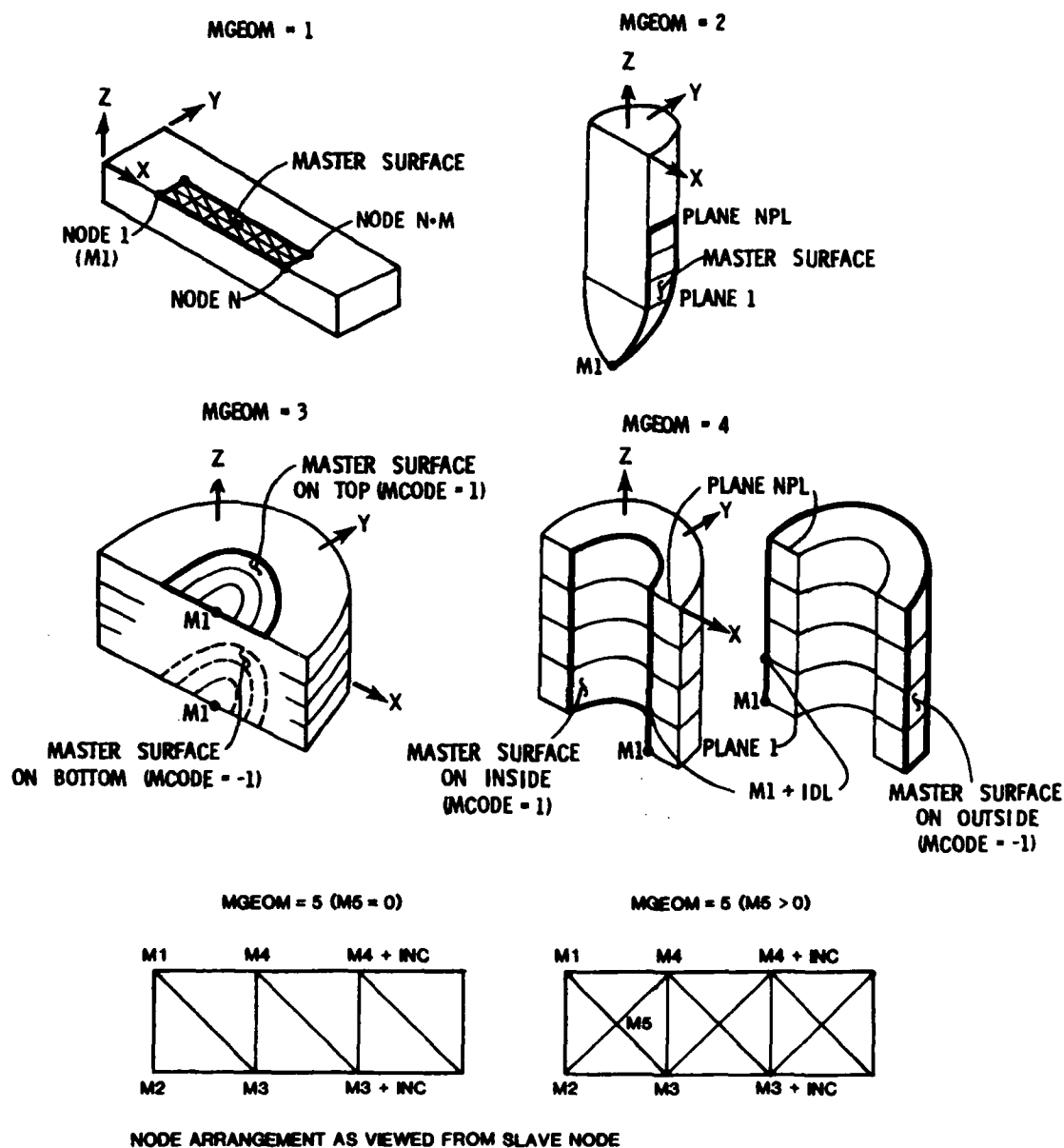


Figure 17. Master Surface Options for Sliding Interfaces



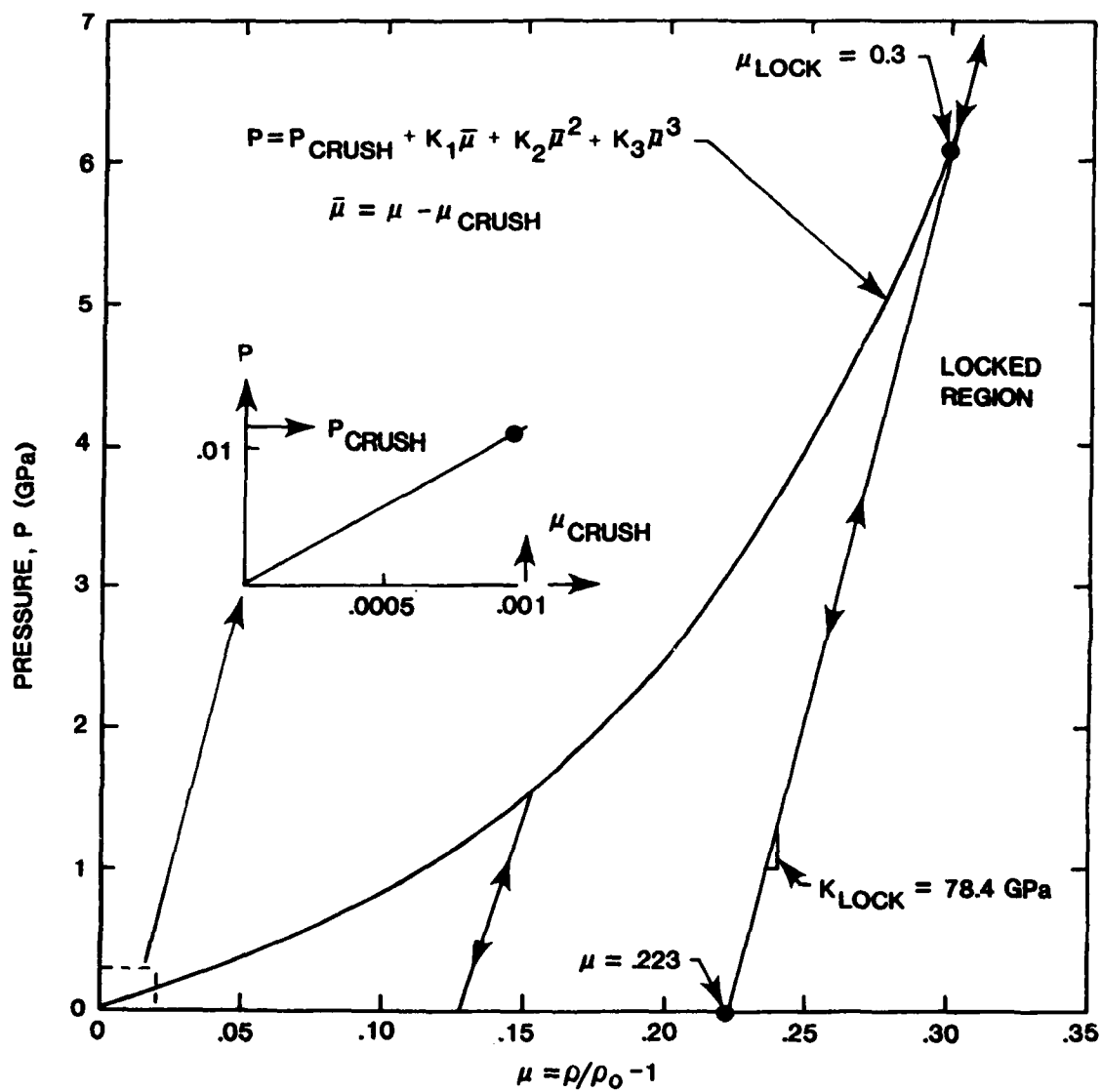


Figure 18. Pressure Model for Crushable Solids. Specific Data Shown are for Concrete

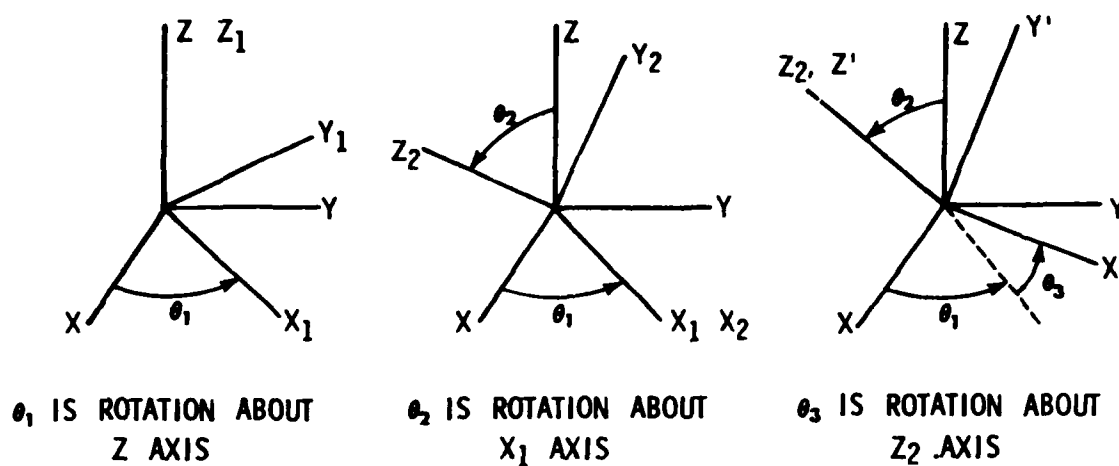


Figure 19. Euler Angles for Principal Material Axes  $X'$ ,  $Y'$ ,  $Z'$  Relative to Initial System Axes  $X$ ,  $Y$ ,  $Z$

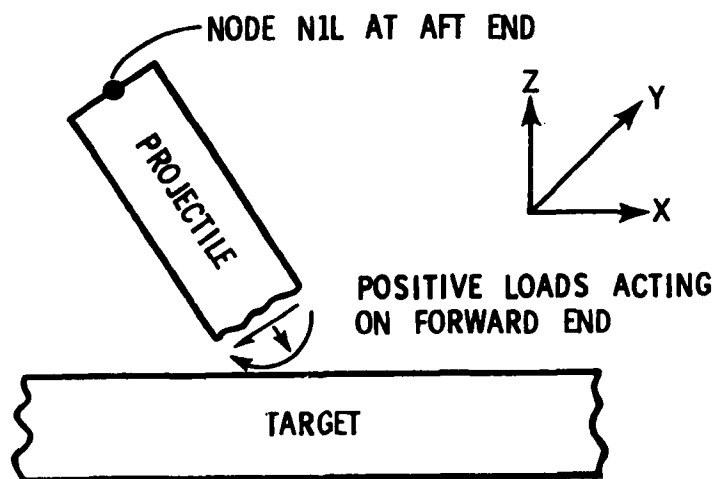


Figure 20. Sign Convention for Internal Loads

## 1. INPUT DATA FOR THE PREPROCESSOR

The functions of the Preprocessor are to define the initial geometry and velocity conditions, and to determine the memory size requirements for the Main Routine. The descriptions which follow are for the data in Figure 1. Consistent units must be used, and the unit of time must be seconds.

It is possible to interject user comments into the data by use of a \$ character. If the \$ is in the first column of the card, that entire card is ignored as input data. If the \$ is beyond the first column in the card, then the \$ and all data to the right of the \$ are ignored.

**Description Card (A80)** – A description of the problem provided by the user.

**Miscellaneous Card (14I5)** –

CASE	=	Case number for run identification.
PRINT	=	<div><div>0 will not print individual data for each node and element.</div><div>1 will print individual node and element data, and complete sliding interface data.</div><div>2 will print node data for nodes with <math>y = 0</math> and element data for elements with one face on the <math>y = 0</math> plane.</div></div>
SAVE	=	<div><div>0 will not write results on restart file.</div><div>1 will write on restart file.</div></div>
NSLID	=	Number of sliding surfaces.
XYZRIG	=	<div><div>100 gives a rigid frictionless surface on the positive side of the plane described by <math>x = 0</math>. If the equations of motion cause a node to have a negative <math>x</math> coordinate, then the <math>x</math> coordinate is set to zero and the <math>x</math> velocity is also set to zero. NABOR nodes with an <math>x</math> coordinate less than one radius have the <math>x</math> coordinate set to one radius and the <math>x</math> velocity set to zero.</div><div>10 gives a rigid frictionless surface at <math>y = 0</math>.</div><div>1 gives a rigid frictionless surface at <math>z = 0</math>.</div><div>0 or blank will ignore this option.</div><div>These options can be combined by addition. For example, 111 gives rigid frictionless surfaces on all three major planes.</div></div>

- SPLIT** = 0 will perform the sliding surface computations after the updated velocities and displacements are determined from the usual equations of motion. Contact is established as long as the slave node interferes with the master surface before the velocities and displacements are adjusted in the sliding surface routines. This option is the most reliable and should be used for complicated sliding surfaces, which include double pass and intersecting sliding surfaces. It must be used for the eroding interface option. For relatively low velocity impact problems, where there is limited deformation, this option can introduce significant errors in the form of excessive deformation and internal energy. A double pass sliding surface is a pair of sliding surfaces that have the role of Master and Slave interchanged. The two sliding surface passes, one from each sliding surface, prevent either surface from penetrating the other.
- SPLIT** = 1 will perform the sliding surface computations after the updated velocities are determined but before the updated displacements are determined. This should be used if the sliding surfaces do not require a double pass or the eroding interface option. Contact is first established when the slave node interferes with the master surface. Thereafter, a slave node is considered to be in contact until the preadjusted normal velocities between the two surfaces are separating rather than closing. This approach minimizes the distance the slave node is moved to place it on the master surface and is therefore more accurate. If there are no sliding surfaces, either option can be used (**SPLIT** = 0 or **SPLIT** = 1).
- N1R** = The first node in a series of consecutive nodes, which act as a rigid body. This option automatically restrains the nodes in the y direction and leaves them free to move in the x and z directions. The rigid body nodes cannot be restrained in either the x or z directions and they cannot be designated as slave nodes on sliding surfaces.
- NNR** = The last rigid body node. All nodes from **N1R** to **NNR** are treated as a rigid body. This node number can control the required bandwidth since the minimum number of nodes in memory must be at least equal to **NNR**.
- N1L** = The node number of the innermost node at the top free end of a cylindrical projectile. This is used if it is desired to compute internal loads in a slender projectile. If this option is used, the nodal geometry must be consistent with the arrangement of nodes generated by the rod node generator described later. Leave blank if not used.
- NOR** = The outer ring number of the rod if internal loads are requested.

- NIR = The inner ring number of the rod.
- NPL = The number of planes of nodes in the rod for the internal loads.
- UNIT = { 0 indicates the constants in the material library have English units (pound/inch/second/degree Fahrenheit).  
1 indicates the constants in the material library are converted to Standard International (SI) units.
- NRST = Number of groups of nodes to have restraints redefined.

**Material Data Cards** – Material data can be defined by the user or taken from the material data library. Specific instructions are presented later. End material data with a blank card.

**Projectile Scale/Shift/Rotate Card (7F10.0) –**

- XSCALE = Factor by which the x coordinates of all projectile nodes are multiplied. Applied after the coordinate shifts (XSHIFT, ZSHIFT) described later. Must use XSCALE = YSCALE = ZSCALE = 1.0 if any NABOR nodes are used.
- YSCALE = Factor by which the y coordinates are multiplied.
- ZSCALE = Factor by which the z coordinates are multiplied.
- XSHIFT = Increment added to the x coordinates of all projectile nodes (length). Applied before the scale factors (XSCALE, YSCALE, ZSCALE).
- ZSHIFT = Increment added to the z coordinates (length).
- ROTATE = Rotation about the y axis (at  $x = z = 0$ ) of all projectile nodes (degrees). Applied after the coordinate shifts (XSHIFT, ZSHIFT) and the scale factors (XSCALE, YSCALE, ZSCALE). Clockwise, as viewed from a negative y location, is a positive rotation.
- SLANT = The angle (degrees) used to redefine the x coordinates of all projectile nodes with the relationship  $X_{\text{new}} = X_{\text{old}} + Z \tan (\text{SLANT})$ . This takes vertical lines of nodes and aligns them at an angle, SLANT, with the vertical. Applied after the other SCALE/SHIFT/ROTATE operations.

**Node Data Cards for Projectile** – These cards are required to define the projectile nodes. If a node is at the interface of the projectile and the target and contains mass from both the projectile and the target, it must be included with the projectile nodes. The nodes will be numbered consecutively. Specific instructions for node input data are presented later. End projectile node data with a blank card. Include blank card even if there are no projectile nodes.

**Target Scale/Shift/Rotate Card (7F10.0)** – Same as Projectile Scale/Shift/Rotate Card except it applies to the target nodes. Must be included even if there are no target nodes.

**Node Data Cards for Target** – Similar to node data cards for projectile. Specific instructions are presented later. End target node data with a blank card. Include blank card even if there are no target nodes.

**Element Data Cards for Projectile** – These cards are required to define the projectile elements. The element numbers will be numbered consecutively. Specific instructions are presented later. End projectile element data with a blank card. Include blank card even if there are no projectile elements.

**Element Data Cards for Target** – Similar to element data cards for projectile. Specific instructions are presented later. End target element data with a blank card. Include blank card even if there are no target elements.

**Sliding Surface Identification Card (10I5, 3F10.0)** – Each sliding surface contains one Identification Card, one or more Master Definition Cards and cards (if required) describing the slave nodes. If there is more than one sliding surface, all data for the first surface are input before beginning data for the second surface. The sliding surfaces should be input in order of the maximum node number on each sliding surface. The mass and spacing of the slave nodes should not be significantly greater than that of the master nodes in the initial or deformed geometry unless a double pass is used. Also, the slave nodes cannot be restrained in the z direction. The nodal bandwidth will be set to contain all sliding surface nodes for a specific sliding surface. The user should be familiar with the node generators before proceeding.

**MGEOM** = A code describing the geometry of the master surface. Must be 1, 2, 3, 4, 5, as shown in Figure 17. Specific geometries are described in the Master Definition Cards.

SEEK

A code describing the search routines used to find the appropriate triangular plane on the master surface. Whenever possible use the specialized searches,  $SEEK = (\pm 1, \pm 2, \pm 3)$ . The specialized routines can be used whenever the master surface is a single valued function of two coordinates (i.e., any vertical line parallel to a specified axis must not pass through the master surface at more than one point). For eroding sliding surfaces set  $SEEK = 4$ .

-1 For all slave nodes on the negative x side of the master surface.

1 For all slave nodes on the positive x side of the master surface.

-2 For all slave nodes in the negative y side of the master surface.

2 For all slave nodes on the positive y side of the master surface.

-3 For all slave nodes on the negative z side of the master surface.

3 For all slave nodes on the positive z side of the master surface.

4 For the generalized search routine. Use of this option can require significant additional CPU time. Every master triangular surface is considered for each slave node. If a slave node is contained in the triangular projection (onto a principal plane) of one or more master surface triangles, and if it is close to the triangular plane  $|\delta_n| < REFVEL \cdot DT$ , then the master plane closest to the slave node is selected.  $\delta_n$  is the normal distance between the slave node and the master plane,  $REFVEL$  is the reference velocity given on this card and  $DT$  is the integration time increment. If the slave node projection is not within any master triangular projections but is close normally to at least one triangular plane  $|\delta_n| < REFVEL \cdot DT$ , and if the distance from the slave node projection to the master triangular projection is small,  $|\delta_{edge}| < REFVEL \cdot DT$ , then the master triangle with the smaller  $|\delta_{edge}|$  is selected. More detail is given in Reference 10.

IT

= Number of velocity iterations. Errors in the velocity match lead to errors in the deviator and shear stresses, but generally not the pressure. (For anisotropic materials, if the pressures are determined incrementally, then there can be errors introduced into the pressure.) For high velocity impact, where the pressures are much higher than the deviator and shear stresses, a relatively low value of  $IT = 1$  or  $IT = 2$  can be used. For lower pressure problems, higher values should be used,  $IT = 2$  to  $IT = 5$ . The velocity iterations, and the corresponding searches on the master surface, are performed only for those slave nodes found to be in contact during the first iteration. For sliding surfaces with many slave nodes in contact and many master nodes, high values of  $IT$

can lead to significant increases in CPU time. This is especially true if  $SEEK = 4$ . For the eroding interface option ( $ERODE > 0$ ), use  $IT = 1$ .

- M1           = Node number of the first node on the master surface. These will be defined by the Master Definition Cards. The first node is used to define the master surface, but it may not be the lowest numbered master node.
  
- S1           = The lowest numbered slave node. Leave blank for  $NSN = 0$ .
- SN           = The highest numbered slave node. Leave blank for  $NSN = 0$ .
- NSN          = The total number of slave nodes in the sliding surface. If all nodes between S1 and SN are slave nodes ( $NSN = SN - S1 + 1$ ), no additional input data are necessary. Otherwise, slave nodes are read individually or in groups. For  $NSN = 0$ , the number of slave nodes is calculated to be the number of nodes in the slave box whose dimensions are given on the Slave Node Limits Cards. In some instances groups of nodes are added to those defined by the slave box. Slave nodes cannot be restrained in the z direction.
  
- NSG          = Numbers of groups of slave nodes to be read. If  $NSG = 0$ , the nodes are either consecutive between S1 and SN, or they are read individually, or they are designated by region.
  
- ISR          = 1 will release slave nodes from the plane of symmetry when they interact with master surface. May use in conjunction with  $MGEOM = 2$  for deep penetration problems. Option not used if left blank.
  
- NAB          = 1 when the slave nodes are NABOR nodes; leave blank when slave nodes are regular (not NABOR) nodes. Slave nodes, for a specific sliding surface, must be all of one type.
  
- FRICT        = The coefficient of sliding friction.
  
- REFVEL       = Reference velocity, which when multiplied by the integration time increment, gives a reference distance. Slave nodes are considered to be associated with a particular master plane only when they are within this reference distance. It is recommended that REFVEL be 1.0 to 1.5 times the relative impact velocity, or the detonation velocity of the explosive.
  
- ERODE        = Equivalent plastic strain (or volumetric strain), which if exceeded by any element on the master surface, will cause the element to be completely failed. Subsequently, the master surface will be redefined to go around the failed element. This allows for penetration/perforation of thick plates. If  $ERODE = 0$ , then erosion is not used. The specific erosion algorithm is described in Reference 8.



Because total failure of the elements must be achieved by the eroding interface algorithm, it is important that EFAIL (a material property) be much greater than ERODE.

**Master Definition Card for Plate Geometry (MGEOM = 1) (9I5) -**

- |       |   |  |
|-------|---|--|
| NML   | = | Number of nodes per row of master nodes. NML is equal to N in Figure 17. Each row of master nodes must have the same number of nodes.  |
| NMW   | = | Number of rows of master nodes. NMW is equal to M in Figure 17. Note that a properly described master surface will pass the following test. Place a right-handed triad of orthogonal vectors on node M1. Point the first vector (thumb) away from the master surface towards the slave nodes. Point the second vector (index finger) down the row of nodes starting at M1. The third vector (second finger) will then point in the direction of the remaining rows of nodes. Two of the corner nodes will pass this test when defined as M1 and the other two corner nodes will fail the test. |
| IDL   | = | The node number increment along the rows of master nodes. If M1 = 100, NML = 6, and IDL = 2, then the first row of nodes in the master surface consists of nodes 100, 102, 104, 106, 108, 110. IDL may be negative.  |
| IDW   | = | The node number increment between the first node of each row. If IDW = 20 and M1, NML and IDL are as described in the preceding description of IDL, then the second row of master nodes consists of nodes 120, 122, 124, 126, 128, 130. IDW may be negative.   |
| IDIA  | = | <div style="display: inline-block; vertical-align: middle; font-size: 3em; line-height: 1;">{</div> <div style="display: inline-block; vertical-align: middle;"> <p>1 is for the diagonal orientation shown in Figure 17.</p> <p>2 is for the other diagonal orientation where the diagonals go in the general direction from the first master node to the last master node.</p> </div>  |
| NBOT  | = | Lowest numbered node on the bottom surface. Used only for an eroding plate to detect erosion through the bottom of the plate. All plate nodes equal to or larger than NBOT are considered to be on the bottom of the plate.  |
| NLAST | = | The largest node number which will be on any element on the surface of an eroding sliding surface. Required only for an eroding interface. The largest node number on the plate is adequate but a more precise number can reduce the bandwidth required for the sliding surface. A small estimate of NLAST will result in a small estimate of the required bandwidth, but the bandwidth is checked dynamically during erosion and the problem will stop if not enough memory is available for the bandwidth actually required.   |

- MGNXT = MGEOM for the next geometry describing part of the master surface. Leave blank when the master surface description is complete.
- M1NXT = M1 to be used with the next geometry specified by MGNXT. Leave blank when MGNXT is blank.

**Master Definition Card for Nose-Rod Geometry (MGEOM = 2) (3I5, 2OX, 2I5) —** This option can be used for deep penetration problems when the projectile is significantly harder than the target. The master surface contains all external triangular planes on the nose and specified triangles in the rod. The nose and rod geometry must be consistent with the grid generators in Figure 11 and 12. The first master node, M1, is at the tip of the nose as shown in Figure 17.

For this option the slave nodes are generally in the target. It is recommended that ISR = 1 in the Sliding Surface Identification Card, if there are any restrained nodes on the plane of symmetry at  $y = 0$ . Use of this option will release the restraint when the slave node comes in contact with the master surface.

- NOR = Outer node ring number of the nose and the rod of the projectile.
- NIR = Inner ring number.
- NPL = Number of planes of nodes in the rod included in the master surface. The interface of the rod and the nose is considered to be plane number 1. If NPL = 2, then the master surface would include all the triangular faces on the nose, plus those between the interface plane of nodes and the plane of nodes directly above the interface plane.
- MGNXT,  
M1NXT = Data for additional master surfaces, described previously for MGEOM = 1.

**Master Definition Card for Disk Geometry (MGEOM = 3) (2I5, 15X, 4I5) —** This option can be used if the master surface is on a disk whose nodal arrangement is equivalent to that of the rod generator. (A disk is simply a very short rod or cylinder.) The first node, M1, is at the center of the master surface as shown in Figure 17.

- NRING = Maximum node ring number included in the master surface.
- MCODE =  $\left\{ \begin{array}{l} 1 \text{ indicates the master surface is on the top surface of the disk (the} \\ \text{lower node numbers are on the top)} \\ -1 \text{ indicates the master surface is on the bottom of the disk.} \end{array} \right.$
- NBOT = Lowest numbered node on the bottom surface. Use only for an eroding interface with MCODE = 1 to detect erosion through the bottom of the plate.

NLAST = The largest node number which will be on the surface of an eroding interface. See description given for MGEOM = 1.

MGNXT,  
M1NXT = Data for additional master surfaces, described previously for MGEOM = 1.

**Master Definition Card for Cylinder Geometry (MGEOM = 4) (4I5, 15X, 2I5) —** This option can be used if the master surface is on the inside of a hollow cylinder or the outside of a cylinder. The nodal arrangement of the cylinder must be equivalent to that of the rod generator. The first node, M1, is on the lower end of the cylinder as shown in Figure 17. (Higher node numbers are on the lower end.)

NRING = Nodal ring number of the surface.

NPL = Number of planes of nodes included in the master surface.

IDL = Node number increment in going from one plane of nodes upward to the next plane. If, for instance, there are 17 nodes per plane, then IDL = -17. IDL is always negative since the increment goes from the higher numbered nodes at the bottom to the lower numbered nodes at the top.

MCODE = { 1 indicates the master surface is on the inside of the cylinder. For this option, the first master node, M1, is on the plane of symmetry, on the positive x axis, when the cylinder is in a vertical position about the z axis.  
-1 indicates the master surface is on the outside of the cylinder. For this option the first node is on the negative x axes.

MGNXT,  
M1NXT = Data for additional master surfaces, described previously for MGEOM = 1.

**Master Definition Card for General Geometry (MGEOM = 5) (4I5) —** This option can be used when it is necessary to describe a general master surface which cannot be defined by the other master surface generators (MGEOM = 1, 2, 3, 4). This master surface is defined by a series of individual triangular surfaces, as shown in Figure 17, which are defined in the following card(s). NBOT, NLAST, MGNXT and M1NXT have all been previously defined for MGEOM = 1.

**Individual Master Surface Card(s) for MGEOM = 5 (7I5) —** This card describes one or more triangular surfaces which form all or a part of a master surface. Use as many cards as necessary and terminate the series of cards with a blank card.

- NCOMP** = Number of composite groups of triangular surfaces to generate. Each composite group contains one ( $M4 = 0$ ), two ( $M4 > 0$  and  $M5 = 0$ ), or four ( $M5 > 0$ ) triangles. In Figure 17,  $NCOMP = 3$  for both cases shown.
- M1** = Number of first node. Nodes M1, M2, and M3 must be counterclockwise when viewed from the slave node side of the master surface.
- M2** = Number of second node.
- M3** = Number of third node.
- M4** = Number of fourth node. If  $M4 = 0$ , only one triangle will be generated for each composite group of triangles. If  $M4 > 0$  and  $M5 = 0$ , then M1, M2, M3 and M4 must be counterclockwise, and two triangles (M1, M2, M3 and M1, M3, M4) are generated for each composite group, as shown in Figure 17.
- M5** = Number of fifth node. If  $M5 = 0$ , only one or two triangles are formed for each composite group of triangles. If  $M5 > 0$ , then four triangles are generated for each composite group of triangles, as shown in Figure 17.
- INC** = Node number increment (positive or negative) between corresponding nodes in each composite group of triangular elements. May be left blank for consecutive numbering ( $INC = 1$ ).

**Slave Node Limits Card for NSN=0 (6E10.0)** – All nodes found in or on the box are taken to be slave nodes for the sliding surface. No other slave node cards may be used with this card.

- XMAX** = Maximum x coordinate of slave node box.
- XMIN** = Minimum x coordinate of slave node box.
- YMAX** = Maximum y coordinate of slave node box.
- YMIN** = Minimum y coordinate of slave node box.
- ZMAX** = Maximum z coordinate of slave node box.
- ZMIN** = Minimum z coordinate of slave node box.

**NBOX** = 1 will read another Slave Node Limits Card to add another box of slave nodes. Leave blank if there are no more boxes of slave nodes to be added.

**NSG Grouped Slave Node Cards for NSG >0 (3I5)**

**S1G** = The first node in a group of nodes.

**SNG** = The last node in a group of nodes.

**INC** = The increment (positive or negative) between the slave nodes. If S1G = 100, SNG = 120, and INC = 5, then nodes 100, 105, 110, 115, 120 will be designated as slave nodes.

**Individual Slave Node Cards for NSN > 0 and NSG = 0 (16I5)** – Individual slave nodes are read if the slave nodes are not consecutive between S1 and SN, and if they are not read in groups (NSG = 0), and if they are not read in by region (NSN > 0).

**S1... SN** = Individual slave nodes read in ascending order.

**Restrained Nodes Identification Cards (2I5, 2X, 3I1)** – Each set of restrained nodes contains one Restrained Nodes Identification Card and additional cards to specify the nodes. The program does not impose any constraint on the number of sets and each set can contain as many as the node arrays can handle. If there are no restrained node sets (NRST = 0 in Miscellaneous Card), this group of cards is omitted. If there is more than one set of restrained nodes, all cards for the first set are entered before the Restrained Nodes Identification Card for the next set is entered. This input redefines the restraints on the designated nodes (it does not simply add to existing restraints). They must be read in ascending order.

**NFN** = Number of nodes in set.

**NFG** = Number of groups of nodes to be read. If NFG = 0 the nodes are read individually.

**IX, IY, IZ** = 1 restrains nodes in X, Y, Z directions, respectively. Expanded description given for Line of Nodes Description Card in Node Geometry Subsection.

**Individual Restrained Nodes Cards - For NFG = 0 (16I5) -**

F1...FN       = Individual nodes to be restrained in ascending order.

**NFG Group Restrained Nodes Cards (3I5) -**

F1G           = First node in the group of nodes to be restrained.

FNG           = Last node in the group of nodes to be restrained. (May be zero if there is only one node in the group.)

INC           = Increment between nodes in the group of restrained nodes. (May be zero if the increment is one or if no increment is needed.)

**Detonation Card (4F10.0) - Leave card blank if no explosives are used.**

XDET          = x coordinate of detonation for high explosive (distance).

YDET          = y coordinate of detonation (distance).

ZDET          = z coordinate of detonation (distance).

TBURN         = Time at which the detonation begins at XDET, YDET, ZDET.

**Initial Velocity Card (7E10.0) -** This card describes the initial velocity conditions of the projectile and the target. If there are interface nodes which include mass from both the projectile and the target, the velocities of these nodes are adjusted by the program to conserve momenta.

PXDOT         = Projectile velocity in the x direction (distance/time).

PYDOT         = Projectile velocity in the y direction.

PZDOT         = Projectile velocity in the z direction.

TXDOT         = Target velocity in the x direction.

TYDOT         = Target velocity in the y direction.

TZDOT         = Target velocity in the z direction.

DT1           = Integration time increment for the first cycle. This must be less than the time required to travel across the minimum altitude of each tetrahedral element at the sound speed of the material in that element.

### **a. Material Descriptions**

A summary of input data for material descriptions is given in Figure 2. Four material types are available: solids, explosives, crushable solids and anisotropic solids.

**Material Cards for Solids from Library (4I5, 2F5.0)** – Data for some materials are available from the material library in subroutine MATLIB. The specific materials are listed as output from the Preprocessor. Library materials may be used directly without being called by this card. If they are called by this card, however, the material data will be printed as part of the output. This card also allows the user to make some decisions regarding fracture options. The user should read the comments in subroutine MATLIB to obtain the references from which the data were generated.

MATL	=	Material identification number. It must be in the range of 1 through 50 and must correspond to a material number in the library.
0	=	Code to specify library material.
IDAM	=	1 will compute material damage. The option in the library is IDAM = 0, which will not compute damage.
IFAIL	=	<div><div>0 will not allow failure of the material when the damage exceeds 1.0, but rather will continue to accumulate the damage. This is the option which is in the library.</div><div>1 will allow the material to fracture partially when the damage exceeds 1.0. Partial fracture causes shear and tensile failure, so only compressive hydrostatic pressure capability remains.</div></div>
DFRAC	=	Factor by which library fracture strain constants (D1, D2, EFMIN – defined later) are multiplied. If left blank, (DFRAC = 0) factor will be set to DFRAC = 1.0.
EFAIL	=	Equivalent plastic strain (or volumetric strain), which, if exceeded, will totally fail the element such that it produces no stresses or pressures. If left blank, the library values of EFAIL = 999 will govern.

**Five Material Cards for Solid Input Data [4I5, 5X, F5.0, A48/4(8F10.0)]** – These five cards specify all the material constants for a solid material. These cards will supersede any material library data with the same material number, MATL. Only previously undefined variables will be defined.

DENSITY	= Material density (mass/volume).
SPH HEAT	= Specific heat (work/mass/degree).
CONDUCT	= Thermal conductivity (power/distance/degree).
ALPHA	= Volumetric coefficient of thermal expansion (degree <sup>-1</sup> ).
TEMP1	= Initial temperature of the material (degree).
TROOM	= Room temperature (degree).
TMELT	= Melting temperature of the material (degree).
X1	= Extra material constant stored in the C9 array (not currently used).
SHEAR MOD	= Shear modulus of elasticity (force/area).
C1, C2, N, C3, M, C4, SMAX	= Constants to describe the material strength, $\sigma$ . The primary form of the strength equation is

$$\sigma = [C1 + C2 \cdot \epsilon^N][1 + C3 \cdot \ln \dot{\epsilon}^*][1 - T^*M] + C4 \cdot P \quad (1)$$

Where  $\epsilon$  is the equivalent plastic strain,  $\dot{\epsilon}^* = \dot{\epsilon}/\dot{\epsilon}_0$  is the dimensionless strain rate for  $\dot{\epsilon}_0 = 1.0 \text{ s}^{-1}$ ,  $T^*$  is the homologous temperature, and  $P$  is hydrostatic pressure (compression is positive).  $N$  must be a positive number, and the thermal softening fraction,  $K_T = [1 - T^*M]$ , is set to  $K_T = 1.0$  when  $M = 0$ . If SMAX is input as a positive number, then the maximum strength for  $\sigma$  is limited to SMAX. If left blank (SMAX = 0) the strength ( $\sigma$ ) is not limited. A more detailed description of the strength model and data is given in Reference 4.

A constant flow stress can be obtained by setting C1 to the flow stress,  $N = 1.0$ , and  $C2 = C3 = C4 = \text{SMAX} = M = 0$ . C1, C2 and SMAX have units of stress (force/area) and the others are dimensionless.

K1, K2, K3	= Cubic coefficients for the Mie-Gruneisen equation of state (force/area)
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$$P = (K1\mu + K2\mu^2 + K3\mu^3)(1 - \Gamma\mu/2) + E_g(1 + \mu) \quad (2)$$

where  $\mu = \rho/\rho_0 - 1$  and  $E_g$  is internal energy per initial volume.

$\Gamma$	= Gruneisen coefficient for Mie-Gruneisen equation of state.
CL	= Linear artificial viscosity coefficient (CL $\approx$ 0.2).



- CQ = Quadratic artificial viscosity coefficient (CQ  $\approx$  4.0).  
 PMIN = Maximum hydrostatic tension allowed (force/area).  
 CH = Hourglass artificial viscosity coefficient for quad elements (CH  $\approx$  0.02).  
 D1...D5 = Constants for the fracture model (Reference 6).

$$\epsilon^f = [D1 + D2 \exp^{D3 \sigma^*}][1 + D4 \cdot \ln \epsilon^*][1 + D5 \cdot T^*] \quad (3)$$

Where  $\epsilon^f$  is the equivalent strain to fracture under constant conditions of the dimensionless strain rate,  $\dot{\epsilon}^*$ , homologous temperature,  $T^*$ , and the pressure-stress ratio,  $\sigma^* = \sigma_m / \bar{\sigma}$ . The mean normal stress is  $\sigma_m$  and  $\bar{\sigma}$  is the von Mises equivalent stress. Expression is valid for  $\sigma^* \leq 1.5$ . Damage is computed from  $D = \Sigma \Delta \epsilon / \epsilon^f$ , and fracture is allowed to occur when  $D = 1.0$ .

- SPALL = Tensile spall stress (negative pressure) at which fracture can occur (force/area).  
 EFMIN = Minimum fracture strain allowed. For  $\sigma^* > 1.5$ ,  $\epsilon^f$  varies linearly from  $\epsilon^f$  at  $\sigma^* = 1.5$  to EFMIN at  $\sigma_m = \text{SPALL}$ .  
 X2 = Extra material constant stored in the C10 array.

**Material Cards for Explosives from Library (2I5)** — Similar to the cards for the solid materials in the library except that no options are provided for fracture.

**Three Material Cards for Explosives Input Data (2I5, 20X, A48/6F10.0/7F10.0)** — Only new variables will be defined. See solid material definitions for other variables.

- ENERGY = Initial internal energy in explosive,  $E_0$  (energy/volume).  
 DET VEL = Detonation velocity, D (distance/time).  
 C1...C5 = Constants for the JWL equation of state. If left blank, a gamma law equation of state is used where

$$\gamma = \sqrt{1 + D^2 \rho / 2E_0} \quad (4)$$

For gamma law the pressure is determined from

$$P = (\gamma - 1)E / \bar{V} \quad (5)$$

For JWL the pressure is determined from

$$P = C1 \cdot (1 - C5/C2 \bar{V}) \cdot \exp(-C2 \cdot \bar{V}) + C3 \cdot (1 - C5/C4 \bar{V}) \cdot \exp(-C4 \cdot \bar{V}) + C5 \cdot E / \bar{V} \quad (6)$$

where  $E$  is internal energy per initial volume and  $\bar{V} = V/V_0$  is the relative volume.  $C1$  and  $C3$  have the units of pressure (force/area) and  $C2$ ,  $C4$ ,  $C5$  are dimensionless.

- X1, X2 = Extra material variables stored in arrays C6 and C7.

**Material Cards for Crushable Solids from Library (215, 15X, F5.0)** — These cards are similar to the cards for other library materials. Total failure is allowed through EFAIL, but fracture due to damage is not allowed.

**Four Material Cards for Crushable Solids Input Data [215, 15X, F5.0, A48/3F10.0/2(8F10.0)]** — These four cards specify the material constants for a crushable solid material (Reference 5). Only new variables will be defined. See previous material definitions for other variables.

- C1, C4 = Constants to describe the material strength,  $\sigma$ .
- $$\sigma = C1 + C4 \cdot P \quad (7)$$
- SMAX = Maximum strength allowed (force/area). If left blank (SMAX = 0), strength ( $\sigma$ ) is not limited.
- PCRUSH, UCRUSH, K1, K2, K3, KLOCK, ULOCK = Constants to describe the pressure, P. The model, and specific data for concrete, are shown in Figure 18. The basic model can also be used for other crushable solid materials. PCRUSH, K1, K2, K3 and KLOCK have units of pressure (force/area). UCRUSH and ULOCK are dimensionless.
- X1 = Extra material constant stored in the D1 array.

**Eight Material Cards for Each Anisotropic Material [415, 5X, F5.0, A48/3F10.0/2(6F10.0)/2(8F10.0)]** — Some special comments are as follows: If K1 = 0 an isotropic pressure, P\*, is determined from the linear elastic constants. For this option, there are no energy effects and the pressure is defined by

$$P = P^* + K2\mu^2 + K3\mu^3$$

where K2 and K3 are isotropic coefficients and  $\mu = \rho/\rho_0 - 1$ . Generally, one should set K2 = K3 = 0 since there is no sound basis for higher order isotropic pressure terms in anisotropic materials. If K1 = 0 and  $\Gamma = 0$ , P\* is computed directly from the strains and is valid only for small strains. If K1 = 0 and  $\Gamma = 1.0$ , P\* is computed incrementally and large strains can be accommodated. If incremental pressures are determined for elements containing nodes on a sliding surface, errors can be introduced if the displacements are not consistent with the velocities. This can occur if there is not a good velocity match on the sliding surface. Also, for K1 = 0 and  $\Gamma = 1.0$ , no external pressures can be applied since an external pressure array is used to store P\* between cycles. For K1 > 0, the isotropic Mie-Gruneisen Equation of State is used for the pressure. This option can be used if it is desirable to include energy effects in the pressure computation.

- $\theta_1, \theta_2, \theta_3$  = Euler angles between the system axes and the material axes. The material input data to follow should be relative to the system coordinate axes. If its initial orientation does not coincide with the system axes, then the Euler angles are used to define the initial orientation. See Figure 19 for definition of the angles. For an anisotropic rod which is rotated from vertical to 30 degrees from vertical, ( $\theta_y = -30$  degrees in x-z plane) the corresponding Euler angles are  $\theta_1 = 90^\circ$ ,  $\theta_2 = -30^\circ$  and  $\theta_3 = -90^\circ$ .
- $\nu_{xy}, \nu_{yz}, \nu_{zx}$  = Three Poisson's ratios. Note that  $\nu_{xy}$  is defined as the relative decrease in the y direction due to a tensile increase in the x direction.

$E_x, E_y, E_z$	=	Moduli of elasticity in the three principal directions.
$G_{xy}, G_{yz}, G_{zx}$	=	Shear moduli of elasticity in the three principal planes (force/area).
X-YIELD	=	Tensile flow stress in the x direction (force/area).
Y-YIELD	=	Tensile flow stress in y direction.
Z-YIELD	=	Tensile flow stress in z direction.
XY-YIELD	=	Shear flow stress in the x-y plane (force/area).
YZ-YIELD	=	Shear flow stress in y-z plane.
ZX-YIELD	=	Shear flow stress in z-x plane.

It should be noted that the algorithm to find the yield surface may not converge if the individual tensile flow stresses (or individual shear stresses) vary by more than a factor of 1.5 to 2.5. When this occurs, an approximate radial return method is used and a warning message is printed in the cycle output data.

#### **b. Node Geometry**

A summary of input data for nodal geometry is given in Figure 3. Nodes may be input as a line of nodes, and/or special shapes consisting of rods, various nose geometries, flat plates and spheres. There is no limit to the number of shapes included for the projectile or the target. In all cases the nodes are numbered consecutively. If a node is at the interface of the projectile and the target and contains mass from both the projectile and the target, it must be included with the projectile nodes.

**Line of Nodes Description Card (2I5, 6F10.0, F7.0, 3I1) –** One card is required for each line of nodes to be generated. Refer to Figure 8 for the spacing of the nodes.

1	=	Identification number for line of nodes geometry.
NNODE	=	Number of nodes in the row of nodes. The nodes are numbered consecutively.
X1	=	x coordinate of first node (distance).
Y1	=	y coordinate of first node (distance).
Z1	=	z coordinate of first node (distance).
XN	=	x coordinate of last node (distance). Leave blank if a single node is entered.
YN	=	y coordinate of last node (distance).
ZN	=	z coordinate of last node (distance).

- EXPAND = Factor by which the distance between nodes is multiplied going from the first node to the last node. Leave blank for uniform spacing.
- IX = 1 will restrain all nodes (N1...NN) in the x direction. No restraint if left blank.
- IY = 1 will restrain nodes in y direction.
- IZ = 1 will restrain nodes in z direction.

**Rod Node Identification Card (I5)** – The rod shape geometry descriptions are given in Figure 11. The rod is always generated in a vertical position about the z axis. When viewed from the positive z direction, the nodes are numbered consecutively counterclockwise, inner to outer and downward. Only one-half the rod is generated as shown, and restraints are provided normal to the plane of symmetry. The rotation of the rod for oblique impact is obtained with a Scale/Shift/Rotate Card.

- 2 = Identification number for rod nodes geometry.

**Rod Node Description Card (4I5, 3F10.0) –**

- NOR = Outer node ring number.
- NIR = Inner node ring number. The inner node ring number for a solid rod is 0.
- NPLN = The number of cross-sectional planes of nodes in the rod.
- IRAD =  $\left\{ \begin{array}{l} 0 \text{ gives uniform radial spacing and constant z coordinates at the top and bottom of the rod.} \\ 1 \text{ requires all r and z coordinates at top and bottom of rod to be input individually.} \end{array} \right.$
- ZTOP = The constant z coordinate of the top of the rod for IRAD = 0, or the top centerline z coordinate (if applicable) for IRAD = 1.
- ZBOT = The constant z coordinate at the bottom of the rod for IRAD = 0, or the bottom centerline z coordinate (if applicable) for IRAD = 1.
- EXPAND = Factor by which the distance between corresponding nodes in the vertical direction is multiplied going from top to bottom. Leave blank for uniform spacing in the vertical direction.

**Rod Node Radii Card for IRAD = 0 (4F10.0) –**

- ROTOP = Outer radius of the rod top.
- RITOP = Inner radius of the rod top.

ROBOT = Outer radius of the rod bottom.

RIBOT = Inner radius of the rod bottom.

**Rod Node Top Radii Card(s) for IRAD = 1 (8F10.0) –**

RT(I) = Top radii for each node ring (I = NIR, NOR). Array RT is currently dimensioned for a maximum outer ring number of 16. If NIR = 0, then RT(0) internally set to 0 and I = 1, NOR.

**Rod Node Bottom Radii Card(s) for IRAD = 1 (8F10.0) –**

RB(I) = Bottom radii for each node ring (I = NIR, NOR). Array RB is currently dimensioned for a maximum outer ring number of 16. If NIR = 0, then RB(0) internally set to 0 and I = 1, NOR.

**Rod Node Top Surface Card(s) for IRAD = 1 (8F10.0) –**

ZT(I) = Top z coordinate for each node ring (I = NIR, NOR). If NIR = 0 then ZT(0) = ZTOP in the Rod Node Description Card and I = 1, NOR. Note that the top z coordinates do not all have to be equal as shown in Figure 11, but can be varied to form curved surfaces.

**Rod Node Bottom Surface Card(s) for IRAD = 1 (8F10.0) –**

ZB(I) = Bottom z coordinate for each node ring (I = NIR, NOR). If NIR = 0, then ZB(0) = ZBOT in the Rod Node Description Card and I = 1, NOR.

NOTE: If it is not possible to describe the node geometry of the rod with a single shape, it is possible to use multiple shapes to form a single rod. The nodes must be numbered consecutively, and the radii and the number of node rings must be the same for the individual rod shapes at their interface. Also, ZBOT and ZTOP for adjoining rods should not be identical. ZTOP for the lower rod should be less than ZBOT for the upper rod by the desired node spacing in the z direction.

**Nose Node Identification Card (I5) –** The nose geometry descriptions are given in Figure 12. The nose shape is always generated in a vertical position (pointed downward) about the z axis. When viewed from the positive z direction, the nodes are numbered consecutively, counterclockwise, downward, and inner to outer. Only one-half the nose shape is generated as shown, and restraints are provided normal to the plane of symmetry. The node geometry for the plane of nodes at the rod interface is not generated with the nose generator and must therefore be generated with the rod generator. The number of rings must be identical for the rod and the nose.

3 = Identification number for nose geometry.

**Nose Node Description Card (4I5, 4F10.0) –**

NOR = Outer node ring number.

- NIR = Inner node ring number.
- INOSE = { 1 identifies a conical nose shape.  
2 identifies a rounded nose shape. If the length of the nose is equal to the radius, a spherical shape is generated. When the length is not equal to the radius, the axial coordinates are scaled and the various radii are not changed.  
3 identifies a tangent ogival nose shape.
- IRAD = Radius option. If IRAD = 1, individual radii and z coordinates are input for each ring of nodes. Leave blank (IRAD = 0) for uniform spacing.
- ROTOP = Top outer node radius of nose.
- RITOP = Top inner node radius of nose.
- ZTOP = The z coordinate at the top of the nose. This is identical to ZBOT for the rod interface.
- ZMIN = The z coordinate at the tip of the nose.

**Nose Node Top Radii Card(s) for IRAD = 1 (8F10.0) –**

- RT(I) = Top radius for each node ring (I = NIR, NOR). Array RT is currently dimensioned for a maximum outer ring number of 16. If NIR = 0, then RT(0) internally set to 0 and I = 1, NOR.

**Nose Node ZMIN Card(s) for IRAD = 1 (8F10.0) –**

- ZM(I) = Minimum coordinates for each node ring (I = NIR, NOR). Array ZM is currently dimensioned for a maximum outer ring number of 16. If NIR = 0, then ZM(0) internally set to ZTOP and I = 1, NOR.

**Flat-Plate Node Identification Card (2I5) –** The flat-plate descriptions are given in Figure 13. In all cases, the lines connecting the adjacent corner nodes are parallel to one of the three primary axes. The nodes are generated in rows parallel to the x axis and are numbered consecutively within each row in the direction of the increasing x axis. The TYPE = 1 option generates the nodes in horizontal planes, row by row in the positive y direction and plane by plane in the negative z direction. The TYPE = 2 option generates the nodes in vertical planes; row by row in the negative z direction and plane by plane in the positive y direction. This TYPE = 2 option can sometimes be used to minimize the nodal bandwidth for penetration into thick plates.

- 4 = Identification number for flat-plate geometry.
- TYPE = { 1 generates nodes in horizontal planes  
2 generates nodes in vertical planes

**Flat-Plate Node Description Card for TYPE = 1 (6I5, 5F10.0)** – This option generates nodes in horizontal planes. The following descriptions refer to the upper portion of Figure 13.

- NX                   = The number of nodes in the x direction; in Figure 13, NX = 13.
- NY                   = The number of nodes in the y direction; in Figure 13, NY = 7.
- NZ                   = The number of nodes in the z direction; in Figure 13, NZ = 5.
- NXEND               = The number of nodes in the x direction in each of the two variable x spacing regions. The node at the division between the uniform and the variable spacing sections is included in this number. The spacing is determined by X-EXPAND and the fractional length by X-PART. In Figure 13, NXEND = 4. Depending on whether NX is odd or even, NXEND can have a maximum value of either  $(NX + 1)/2$  or  $NX/2$ , respectively, unless the special option discussed in X-PART is used. The remaining middle x region (if any) is uniformly spaced. Leave blank for uniform spacing in the x direction.
- NYEND               = The number of nodes in the y direction in the variable y spacing region. The node at the division between the uniform and the variable spacing sections is included in this number. Spacing is determined by Y-EXPAND and the fractional length by Y-PART. In Figure 13, NYEND = 4. NYEND can have a maximum value of NY. The remaining y region (if any) is uniformly spaced. Leave blank for uniform spacing in the y direction.
- IY                   = 1 gives restraint in the y direction only if y = 0 (Y1 = 0.0).
- X-EXPAND           = Factor by which the x distance between adjacent nodes changes outward to the ends for each X-PART variable spacing region. Same as described for the Line of Nodes Description Card.
- X-PART               = Fractional part of the total x length of the flat plate occupied by each of the variable x spacing regions. If X-PART = 0.0, the entire spacing in the x direction is uniform. If X-PART = 0.5 and NXEND =  $NX/2$ , the spacing in the positive x direction is variable for entire x length (X1 to XN).
- Y-EXPAND           = Factor by which the y distance between adjacent nodes changes in the increasing y direction for the Y-PART variable spacing region.
- Y-PART               = Fractional part of the total y length of the flat plate occupied by the variable y spacing region.

**Z-EXPAND** = Factor by which the z distance between adjacent nodes changes in the decreasing z direction from Z1 to ZN.

**Flat Plate Node Description Card for TYPE = 2 (6I5, 5F10.0)** – This option generates nodes in vertical planes. See lower portion of Figure 13 for description. Definition of variables is analogous to those of the TYPE = 1 variables.

**Flat-Plate Node Size Card (6F10.0) –**

**X1** = The minimum x coordinate of the plate shape.

**Y1** = The minimum y coordinate of the plate shape.

**Z1** = The maximum z coordinate of the plate shape.

**XN** = The maximum x coordinate of the plate shape.

**YN** = The maximum y coordinate of the plate shape.

**ZN** = The minimum z coordinate of the plate shape.

**Sphere Node Identification Card (I5)** – The cross section of the bottom spherical shape is identical to that shown for the rounded nose shape of Figure 12. The top one-half cross section is initially geometrically symmetric to the bottom. Only one-half of the top and bottom halves are generated, and restraints are provided normal to the vertical plane of symmetry. The sphere is generated with the nodes numbered as two rounded circular noses having an interface between. The top nose is generated first; viewed from the positive z direction, this generation is counterclockwise, upwards and inner to outer. The bottom nose is generated with the interface included with each spherical shell; this generation viewed from the positive z direction is counterclockwise, downwards and inner to outer. A summary of the number of nodes included in the various shapes is given in Figure 16.

**5** = Identification number for sphere geometry.

**Sphere Node Description Card (2I5, 5X, I5, 3F10.0) –**

**NOR** = Outer node ring number.

**NIR** = Inner node ring number.

**IRAD** =  $\begin{cases} 0 & \text{gives R0, RI, ZCG input option for uniform spacing.} \\ 1 & \text{gives RT(I), ZCG input option (I = NIR, NOR).} \end{cases}$

**R0** = Radius of outer node ring.

**RI** = Radius of inner node ring.

**ZCG** = The z coordinate of the center of the sphere.



### **Sphere Node Radii Card(s) for IRAD = 1 (8F10.0) -**

RT(I) = Radii for each node ring (I = NIR, NOR). Array RT is currently dimensioned for a maximum outer ring number of 16. If NIR = 0, then RT(0) internally set to 0 and I = 1, NOR.

**NABOR Filled Plate Node Identification Card (I5) -** Generates nodes for a plate with normal (tetrahedral element) edges and NABOR nodes in the center, as shown in Figure 14, so that penetration problems can have NABOR nodes in the high distortion region and normal elements in the low distortion region. Limited to generating the +Y half of mirror symmetry about Y = 0. The node generation is generally from the center of the plate to the edge. The nodes are generated in a column at a fixed X and Y from the largest Z to the smallest (or most negative) Z. The NABOR nodes are generated first. The column at  $X = (X1 + XN)/2$ ,  $Y = DO/2$  is generated first followed by the other interior NABOR nodes. The exterior layer of NABOR nodes and all the normal nodes are generated in columns in a generally counterclockwise direction. The mass of the NABOR nodes is dependent only on the density of the material and the diameter of the NABOR nodes. They cannot accept mass from attached elements. The diameters of all NABOR nodes in a specific problem must be identical.

The size of the NABOR node region can be calculated from the number of NABOR nodes in each direction and their diameter. See Figure 14 for a typical example. The z dimension has the NABOR nodes stacked in columns but alternate columns are offset by half a diameter. The depth in the z direction is  $(NNZ + 0.5) * DO$ . The y dimension consists of layers of NABOR nodes. The separation between the layers is only  $\sqrt{2/3} * DO$  which makes the y width  $((NNY - 1) * \sqrt{2/3} + 1) * DO$ . The x dimension has both layers and an offset. The distance between columns in the x direction is  $\sqrt{3/4} * DO$ . The offset between layers is  $(\sqrt{1/12}) * DO$ . The x width is  $(NNX * \sqrt{3/4} + \sqrt{1/12}) * DO$ .

6 = Identification number for NABOR filled plate geometry.

### **NABOR Filled Plate Node Description Card (7I5, 5X, 3E10.0) -**

NNX = Number of NABOR nodes in the x direction. This number must be 3 or larger and odd. In Figure 14, NNX = 7.

NNY = Number of NABOR nodes in the y direction. This number must be 3 or larger and odd. In Figure 14, NNY = 5.

NNZ = Number of NABOR nodes in the z direction. This number must be 2 or larger. In Figure 14, NNZ = 3.

MATL = Material number for plate. Used for NABOR nodes.

NXEND = Number of normal nodes on each end in the x direction. In Figure 14, NXEND = 3.

NYEND = Number of normal nodes on the positive y side of the plate. Both NXEND and NYEND must be zero or nonzero together. In Figure 14, NYEND = 3.

- IY** = 1 gives restraint in the y direction if  $Y1 = 0$ .  
**X-EXPAND** = Factor by which the x distance between adjacent nodes changes for the regular (not NABOR) nodes.  
**Y-EXPAND** = Factor by which the y distance between adjacent nodes changes for the regular nodes.  
**DO** = Diameter of the NABOR nodes. The first DO read must be positive. Following DOs may be the same value or the field can be left blank.

**NABOR Filled Plate Size Card (5E10.0) –**

- X1** = The minimum x coordinate of the plate.  
**Y1** = The minimum y coordinate of the plate. When  $NYEND > 0$  then  $Y1$  must be 0.0.  
**ZTOP** = The maximum z coordinate of the plate.  
**XN** = The maximum x coordinate of the plate. The middle column in the plane of nodes which touches the  $y = Y1$  plane is generated at  $(X1 + XN) * 0.5$ . When  $NXEND > 0$ , then the width  $(XN - X1)$  must be larger than  $(NNX + 4) * \sqrt{3/4} * DO$ . When  $NXEND = 0$ , then the plate is all NABOR nodes and the width has already been determined.  
**YN** = The maximum y coordinate of the plate. When  $NXEND > 0$ , the width  $(YN)$  must be larger than  $(NNY + 2) * \sqrt{2/3} * DO$ . When  $NXEND = 0$ , then the plate width has already been determined and  $YN$  is ignored.

The minimum Z coordinate value is  $ZBOT = ZTOP - (NNZ + 0.5) * DO$ .

**NABOR Brick Node Identification Card (I5) –** This option generates a brick shape composed entirely of NABOR nodes as shown in Figure 15. It generates the largest NABOR brick which lies completely within the specified size. The NABOR nodes touch the  $X1$ ,  $Y1$ ,  $Z1$ , planes but may not reach to the  $XN$ ,  $YN$ ,  $ZN$  planes.

- 7** = Identification number for NABOR brick geometry.

**NABOR Brick Node Description Card (2I5, E10.0) –**

- MATL** = Material number for NABOR nodes.  
**IY** = 1 gives restraint in the y direction if  $Y1 = 0$ .  
**DO** = Diameter of the NABOR nodes. The first DO read must be positive. Following DOs may be the same value or the field can be left blank.

X1	=	The minimum x coordinate of the brick shape.
Y1	=	The minimum y coordinate of the brick shape.
Z1	=	The maximum z coordinate of the brick shape.
XN	=	The maximum x coordinate of the brick shape.
YN	=	The maximum y coordinate of the brick shape.
ZN	=	The minimum z coordinate of the brick shape.

### c. Element Geometry

A summary of input data for element geometry is given in Figure 4. Elements may be input as a series of individual or composite elements and/or special shapes of rods, nose geometries, flat plates, and/or spheres. The elements must be assembled in a manner consistent with the previously generated nodal geometry. There is no limit to the number of shapes included for the projectile or the target.

**Series of Composite Elements Description Card (1215)** – Element cards for each Series of Composite Elements are supplied as needed by the user. For this discussion it will be assumed that the elements are entered as a series of composite brick elements, each containing six individual elements as shown in Figure 9. Following this immediate discussion will be an example and instructions for generating a series of individual elements.

1	=	Identification number for a series of composite elements.
NCOMP	=	Number of composite elements in the series.
MATL	=	Material number of the elements. If left blank, the material number from the previous element data card will be used.
N1-N8	=	Node numbers of the first composite brick element as shown in Figure 9. Nodes N1, N2, N3, N4 and nodes N5, N6, N7, N8 are counterclockwise when looking from N1 to N5.
INC	=	The node number increment added to the node numbers of the previous composite brick element for the next composite brick element.

An example of input data for composite brick elements is shown in Figure 10. In the upper left it can be seen that there are four rows of nodes (1 to 4, 5 to 8, 9 to 12, 13 to 16), which are arranged to contain three composite brick elements. If the first element is numbered 1, then the first composite brick contains elements 1 to 6, the second contains 7 to 12, and the third contains 13 to 18. The first composite brick is defined by nodes N1 = 1, N2 = 5, N3 = 9, N4 = 13, N5 = 2, N6 = 6, N7 = 10, and N8 = 14. Note that N1 to N4 and N5 to N8 are counterclockwise when looking from N1 to N5. The six individual elements are generated according to the arrangement and order (A, B, C, D, E, F) shown in

Figure 9. The node numbers for each successive brick are simply  $INC = 1$  greater than those of previous brick. For the second brick, for instance,  $N1 = 1 + 1 = 2$ ,  $N2 = 5 + 1 = 6$ ,  $N3 = 9 + 1 = 10$ ,  $N4 = 13 + 1 = 14$ ,  $N5 = 2 + 1 = 3$ ,  $N6 = 6 + 1 = 7$ ,  $N7 = 10 + 1 = 11$ , and  $N8 = 14 + 1 = 15$ .

It is possible to generate a series of individual tetrahedral elements by letting  $N1$  to  $N4$  be the nodes of the first element, where  $N1$ ,  $N2$ , and  $N3$  are counterclockwise when viewed from  $N4$ . This option is exercised when  $N5$  to  $N8$  are left blank. It is also possible to generate a series of composite wedge elements, each containing three individual tetrahedral elements. The three elements in a composite wedge element are numbered consecutively. If  $N2$  and  $N6$  are left blank, the first three tetrahedron elements (A, B, C) are defined by nodes  $N1$ ,  $N3$ ,  $N4$ ,  $N5$ ,  $N7$  and  $N8$  as shown in Figure 9. Likewise, if  $N4$  and  $N8$  are left blank, the first three elements (D, E, F) are defined by nodes  $N1$ ,  $N2$ ,  $N3$ ,  $N5$ ,  $N6$ , and  $N7$ . Do not use composite wedge elements or individual tetrahedral elements in conjunction with the average pressure option (VRFACT) described in the Main Routine.

**Rod Element Identification Card (I5) –** Elements are generated for the rod shapes illustrated in Figure 11 and described by the Rod Shape Node Cards. The elements are numbered consecutively and are generated in layers of composite brick elements beginning with top layer 1 and ending at bottom layer  $NLAY$ . The entire first layer of elements is generated before the second layer, etc., and the composite brick elements of each layer are generated in a counterclockwise manner for each ring of elements from the inner to the outer ring.

2 = Identification number for rod geometry.

**Rod Element Description Card (5I5) –**

NOER = Outer element ring number.

NIER = Inner element ring number. The inner element ring number for a solid rod is 1.

NLAY = The number of layers of elements in the rod. The total number of elements in a rod shape shown in Figure 11 is dependent on the number of layers and the number of elements per layer. The number of elements per layer is dependent on the inner and outer element ring numbers. [For example: If  $NLAY = 10$ ,  $NIER = 2$  and  $NOER = 5$ , the total number of elements can be determined through use of Figure 16. The number of elements per layer for the solid rod of  $NOER = 5$  is 300, and of  $NIER = 2$  is 48. Therefore, the total of elements for the hollow cylinder is  $10(300-48) = 2520$ .]

$N1$  = The number of the lowest numbered rod node. For the solid rod, this is the centerline node on the top end of the rod. For the hollow rod, this is the innermost clockwise node on the top end of the rod when viewed from the top.

MATL = Material number of a uniform material rod.  $MATL = 0$  gives  $M(I)$  input option ( $I = NIER, NOER$ ), where material numbers for each element ring must be input individually.

**Rod Element Material Card for MATL = 0 (16I5) -**

M(I) = Material number for each element ring (I = NIER, NOER). Array M is currently dimensioned for a maximum outer ring number of 16.

**Nose Element Identification Card (I5) -** Elements are generated for the nose shapes illustrated in Figure 12 and described by the Nose Shape Node Cards. The elements are numbered consecutively and are generated in shells of composite brick elements beginning with the innermost shell and ending with the outermost shell. The entire first shell of elements is generated before the second shell, etc., and the composite brick elements of each shell are generated in a counterclockwise manner for each ring of elements from the top to the bottom of each shell.

3 = Identification number for Nose Geometry.

**Nose Element Description Card (2I5, 5X, 2I5) -**

NOER = Outer element ring number.

NIER = Inner element ring number.

N1 = The number of the lowest numbered nose node. (The nose does not include interface nodes.)

MATL = Material number of a uniform material nose. MATL = 0 gives M(I) input option (I = NIER, NOER), where material number for each element ring must be input individually.

**Nose Element Material Card for MATL = 0 (16I5) -**

M(I) = Material number for each element ring (I = NIER, NOER). Array M is currently dimensioned for a maximum outer ring number of 16.

**Flat-Plate Element Identification Card (2I5) -** The elements are generated for the flat-plate illustrated in Figure 13 and described by the Flat-Plate Shape Node Cards. The elements are numbered consecutively and are generated in rows of composite brick elements. The rows of elements go in the direction of the increasing x axis. The TYPE = 1 option generates the elements in horizontal layers and the TYPE = 2 option generates the elements in vertical layers. Element generation must be consistent with the generation of nodes.

4 = Identification number for flat-plate geometry.

TYPE  $\left\{ \begin{array}{l} 1 \text{ generates elements in horizontal layers.} \\ 2 \text{ generates elements in vertical layers.} \end{array} \right.$

#### **Flat-Plate Element Description Card (5I5) -**

- NLX = Number of layers of composite brick elements in the x direction. The total number of nodes along the x direction must be NLX + 1. In Figure 13, NLX = 12.
- NLY = Number of layers of composite brick elements in the y direction. The total number of nodes along the y direction must be NLY + 1. In Figure 13, NLY = 6.
- NLZ = Number of layers of composite brick elements in the z direction. In Figure 13, NLZ = 4.
- N1 = The node number of the corner node shown in Figure 13.
- MATL = Material number of the flat plate.

**Sphere Element Identification Card (I5) -** Elements are generated for a sphere, the bottom half cross section of which is identical to the rounded nose shown in Figure 12 and described by the Sphere-Shape Nose Cards. When viewed from the top, the elements are consecutively numbered counterclockwise, upwards and outwards for the top one-half and then counterclockwise, downwards and outwards for the bottom one-half.

- 5 = Identification number for sphere shape.

#### **Sphere Element Description Card (2I5, 5X, 2I5) -**

- NOER = Outer element ring number.
- NIER = Inner element ring number. The inner element ring number for a solid sphere is 1.
- N1 = The number of lowest numbered sphere node.
- MATL = Material number of a uniform material sphere. MATL = 0 gives M(I) input option (I = NIER, NOER), where material number for each element ring must be input individually.

#### **Sphere Element Material Card for MATL = 0 (16I5) -**

- M(I) = Material number for each element ring (I = NIER, NOER). Array M is currently dimensioned for a maximum outer ring number of 16.

**NABOR Filled Plate Element Identification Card (I5) -** Elements are generated for the plate surrounding the NABOR nodes, as shown in Figure 14. The inner element layer is generated between the outer layer of NABOR nodes and the first inner layer of normal nodes. The order of generation is similar to the generation of the normal nodes, in layers of columns and generally counterclockwise.

- 6 = Identification for NABOR filled plate shape.

### **NABOR Filled Plate Element Description Card (715) -**

NNX	}	= Identical to input used for corresponding NABOR filled plate node description card.
NNY		
NNZ		
MATL		
NKEND		
NYEND		

N1 = The number of the lowest numbered NABOR node in the plate.

### **2. INPUT DATA FOR THE MAIN ROUTINE**

The function of the Main Routine is to perform the computations. The Main Routine reads initial conditions from the restart tape which must be generated from a Preprocessor run or a previous Main Routine run. The descriptions that follow are for the data in Figure 5. Consistent units must be used.

It is possible to interject user comments into the data by use of a \$ character, as described for the Preprocessor.

**Description Card (A80) -** A description of the problem provided by the user.

### **Identification Card (5I5, 5X, 5F10.0) -**

CASE	=	Case number for run identification.
CYCLE	=	The cycle number at which the restart occurs. The cycle numbers for which restart files are written are given in the printed output of the previous run (Preprocessor or Main Routine).
IPRES	=	{ 0 gives no applied pressures read or applied. 1 will use the pressure data which was input in a previous run. 2 will read applied pressures to be used in subsequent computations.
CHANG	=	{ 0 will not allow problem size to be changed. 1 will allow the problem to be reduced in size at a specified time. 2 will allow the problem size to be reduced at one time, and then increased at another time. The expansions and reductions can be performed in either order. If identical times are designated for the expansion and reduction, the reduction will be performed first. 3 will allow the problem size to be expanded at a specific time.
IHRG	=	1 will use hourglass artificial viscosity when computing brick average pressures for solid materials. Generally not required.

- VFRACT** = Fraction of initial volume of a brick at which individual element pressure is computed. An average pressure is computed for a brick volume larger than VFRACT. Average pressures are not used if VFRACT = 0 or the field is blank. Expanded description given in Reference 8. Use of VFRACT option requires all elements to be input with special shape generators or composite brick elements. No wedges or individual tetrahedral elements are allowed.
- PMAX** = Maximum pressure allowed in any element. Pressure not limited if PMAX = 0 (or blank field).
- VNREF** = Reference closing velocity for NABOR search routines. It should be 0.2 to 1.0 times the impact velocity (or relative closing velocity) in the problem. Lower values will cause less searching but may allow two NABOR nodes to become too close before being detected. Higher values will cause more searching but will also ensure that nodes do not become too close before being detected.
- ARMAX** = For anisotropic materials the maximum angle an element can rotate (in degrees) before recalculating the element axes. A properly chosen value can significantly reduce central CPU time with only a small loss of accuracy. A large value will prevent recalculating element rotations, which will cause all elements to be treated as if they did not rotate. This uses the minimum CPU time and may be suitable for some problems. A small value of ARMAX = 1.0 degree will bypass the lengthy element axis calculation for elements in regions where the nodes do not have significant rotations.
- ASERR** = The maximum relative error allowed when calculating the stress at the yield surface for anisotropic materials. The acceptable band of stresses is from  $1.0 - \text{ASERR}$  to  $1.0 + \text{ASERR}$  times the actual yield stress. When left blank, the value of ASERR = 0.01 will be used.

**Integration Time Increment Card (6F10.0) -**

- DTMAX** = The maximum integration time increment which will be used for the equations of motion.
- DTMIN** = The minimum integration time increment allowed. If exceeded, the results will be written onto the restart tape, and the run will stop.
- SSF** = The fraction of the sound speed transit time used for the integration time increment. It must be less than unity. Generally, SSF = 0.9 can be used, but some conditions (such as eroding interfaces) may require a lower value of SSF = 0.5.



- TMAX** = The maximum time the problem is allowed to run. This time refers to the dynamic response of the system, not the central processor time (CPMAX) described next. The results at time = TMAX are written onto the restart tape, and the run is discontinued.
- CPMAX** = Central Processor time at which the results will be written onto the restart tape and the run will stop. This feature will be bypassed if CPMAX = 0. Time units are defined by subroutine CPCLCK.
- EMAX** = The upper limit for total kinetic energy if applied pressures are included (IPRES = 1 or 2). This is used for numerical instability checks. Run will stop if the kinetic energy exceeds EMAX. Leave blank if there are no applied pressures.

**Pressure Cards for IPRES = 2 (615, F10.0)** – These cards describe the applied pressures and the elements to which they are applied. If other pressures were used previously, they are all deleted, and the only applied pressures which act are those that are input in the current run. End with a blank card.

- ELE1** = The first element in a series of elements, to which pressure is applied. It must not be less than ELE1 or ELEN from a previous Pressure Card.
- ELEN** = The last element in series of elements. It cannot be less than ELE1.
- ELEINC** = The element number increment between ELE1 and ELEN. If ELE1 = 100, ELEN = 120 and ELEINC = 5, then pressures are applied to elements 100, 105, 110, 115, 120.
- N1** = The node number opposite the triangular face of element ELE1 to which the pressure is applied.
- NN** = The node number opposite the triangular face of element ELEN to which the pressure is applied.
- NODINC** = The node number increment between N1 and NN. For the elements described under ELE INC (100, 105, 110, 115, 120), if N1 = 200, NN = 208 and NODE INC = 2, then the pressures are applied to the triangular faces opposite nodes, 200, 202, 204, 206, 208, of elements 100, 105, 110, 115, 120.
- PRES** = The pressures which are applied to the triangular faces of the elements described on this card (force/area).

**Time-Pressure Cards for IPRES = 2 (2F10.0)** – These cards allow the applied pressures to be varied as a function of time. A minimum of two cards must be used, which

span the time from the beginning of the run to TMAX. Program currently dimensioned for a maximum of 50 cards. End with a blank card.

**PTIME** = The time corresponding to P(T). Cards must be input in order of increasing time.

**P(T)** = The factor by which all pressures are multiplied at the corresponding time. Intermediate values are linearly interpolated between values at specified times.

**Change Card for CHANG = 1 or 2 (F10.0, 1015)** – This card is used only if changes are to be made which reduce the size of the problem. The portions of the problem which remain are those which were input first. Common uses are to drop the explosive gases after a liner has been accelerated, or to drop the target after a projectile has perforated the target. For CHANG = 1 the problem size is reduced only and there are no expansions. For CHANGE = 2 there will be problem expansions as well as problem reductions.

**TDROP** = Time at which change occurs.

**NODE** = Total number of nodes which remain in the revised problem.

**PNODE** = Number of projectile nodes which remain in the revised problem.

**ELE** = Total number of elements which remain in the revised problem.

**PELE** = Number of projectile elements which remain in the revised problem.

**NSLID** = Number of sliding surfaces which remain in the revised problem.

**NPLOT** = Number of nodes for which time-history data are written, which remain in the revised problem.

**LPLOT** = Number of elements for which time-history data are written, which remain in the revised problem.

**NFAIL** = Number of elements which will be designated to fail totally. This type of failure sets all stresses in the element to zero. It essentially makes the element disappear except that mass is retained at the nodes.

**NAB** = Total number of NABOR nodes which remain in the revised problem.

**PNAB** = Number of projectile NABOR nodes which remain in the revised problem.

**Designated Element Failure Card for NFAIL > 0 (16I5)** – This card is used only if there are elements to be totally failed.

EF1 ... EFN                    = Elements to be totally failed in the revised problem.

**Change Add Card for CHANG = 2 or 3 (F10.0,6I5)** – This card is used only if there are additions to be made to the problem. These additions can be made in conjunction with previous problem reductions (CHANG = 2) or they can be made to the original problem (CHANG = 3).

TADD                            = Time at which the change (problem size expansion) occurs.

NSLID                          = Number of sliding surfaces in the expanded problem. If this is greater than the existing numbers of sliding surfaces, the program will read input data for the additional sliding surfaces.

XYZRIG                        = Code to allow for rigid frictionless surfaces on positive sides of planes at  $x=0$ ,  $y=0$  and/or  $z=0$ . See description given in the Miscellaneous Card in the Preprocessor. It must be input here even if input in the Preprocessor

SPLIT                          = 0 or 1. See description given in the Miscellaneous Card in the Preprocessor.

N1R, NNR                      = First and last rigid body nodes as described in the Miscellaneous Card in the Preprocessor. They must be input here even if input in the Preprocessor.

N1L, NOR, NIR, NPL = Node geometry descriptions if internal loads are desired. See description given in the Miscellaneous Card in the Preprocessor. They must be input here even if input in the Preprocessor.

NRST                          = Number of groups of nodes to have restraints redefined.

IPRINT                        = { 0 will not print any node or element data  
                                  1 will print data for all nodes and elements  
                                  2 will print data for all nodes at  $y=0$  and all elements with one face at  $y=0$   
                                  3 will print data for all added nodes and elements  
                                  4 will print data for all added nodes at  $y=0$  and all added elements with one face at  $y=0$

**Target Scale/Shift/Rotate Card for CHANG=2 or 3 (F10.0)** – This card is the same as used in Preprocessor. Applied to added target nodes only in the expanded problem. Must be included even if there are no additional nodes to be input.

**Additional Target Node Data for CHANG=2 or 3** – These cards are required to define the additional nodes (for target only) for the expanded problem. Same format as used in Preprocessor. End with a blank card. Include blank card even if there are no additional target nodes.

**Additional Target Element Data for CHANG=2 or 3** – These cards are required to define the additional elements (for target only) for the expanded problem. Same format as used in the Preprocessor. End with a blank card. Include blank card even if there are no additional target elements.

NSLID, NRST data read as required. Same format as used in Preprocessor.

**Target Velocity Card for CHANG=2 or 3 (30X, 3F10.0)** – This card defines the nodal velocities of added target nodes only in the expanded problem. See descriptions for Velocity/Detonation Card in Preprocessor. Must be included even if there are no target nodes or if no additional target nodes were input. If there are no target velocities, do not leave the card blank. Instead, input velocities as 0. Must be followed by a blank card.

**Plot Card (5I5, 5X, 4F10.0) –**

CYCLE	=	Same restart cycle as specified on the Identification Card.
SYS	{	0 will not write the system data on the Plot Tape. 1 will write all the system data on the Plot Tape.
LOAD	{	0 will not write the internal loads data on the Plot Tape. 1 will write all the internal loads data on the Plot Tape. This option can only be used if N1L, NOR, NIR and NPL are properly defined in the Preprocessor Miscellaneous Card.
NPLOT	=	The number of nodes whose data will be written on the Plot Tape. The individual nodes are specified on the Designated Nodes Cards.
LPLOT	=	The number of elements whose data will be written on the Plot Tape. The individual elements are specified on the Designated Elements Cards.
DT SYS	=	The time increment at which the System and Internal Loads data are written on the Plot Tape (time). These quantities do not vary as rapidly as do the individual node and element data so a larger time increment can be used.
TSYS	=	The time at which the first System and Internal loads data are written on the Plot Tape. If left blank, the time at the beginning of the Main Routine run will be used (time).
DT NODE	=	The time increment at which the Individual Node and Element data are written on the Plot Tape (time). These quan-

ties vary more rapidly than the System and Internal Loads data so a smaller time increment can be used.

**TNODE** = The time at which the first Individual Node and Element data are written on the Plot Tape (time).

**Designated Nodes Cards (16I5)** – This card is used only if there are node data to be written on the plot tape (NPLOT > 0 on the plot card).

**N1 ... NN** = Individual node numbers whose data will be written on the Plot Tape. They must be in ascending order.

**Designated Elements Cards (16I5)** – This card is used only if there are element data to be written on the plot tape (LPLOT > 0 on the plot card).

**E1 ... EN** = Individual element numbers whose data will be written on the Plot Tape. They must be in ascending order.

**Data Output Cards (2F10.0, 3I5)** – These cards are used to specify various forms of output data at selected times, and the last card must be for a time greater than TMAX even though output will not be provided for that specific time. Recall that output is automatically provided at TMAX and a data output card need not be provided for this time. End run with a blank card.

**TIME** = Time at which output will be provided.

**ECHECK** = A code which governs the printed output. Three options are provided:

- (1) If ECHECK is greater than 1000, the individual node and element data will not be printed. Only system data such as centers of gravity, energies, momenta, and net velocities are provided for the projectile, target, and total system.
- (2) If ECHECK = 999, system data will be printed as will nodal data on the plane of symmetry at  $y=0$ . Element data will not be printed.
- (3) If ECHECK is less than 999, the system data and individual node data will be printed. Individual element data will be printed for all elements which have an equivalent plastic strain equal to or greater than ECHECK. For example, if ECHECK = 0, all element data will be printed. If ECHECK = 0.5, only those elements with equivalent plastic strains equal to or greater than 0.5 will have data printed.

**NOTE:** There are some instances when data are printed even though not specified with a data output card. If the min-

imum time increment, **DTMIN**, is violated, or the specified central processor time, **CPMAX**, is exceeded, or the maximum run time, **TMAX**, is achieved, the results are written on the restart tape. The value of **ECHECK** used for the printed output is that value which is on the following data output card.

LOAD	$= \begin{cases} 0 & \text{will not print internal loads data.} \\ 1 & \text{will print internal loads in a slender projectile. This option can only be used if N1L, NOR, NIR and NPL are properly defined in the Preprocessor Miscellaneous Card.} \end{cases}$
SAVE	$= \begin{cases} 0 & \text{will not write results on the restart tape.} \\ 1 & \text{will write results on the restart tape.} \end{cases}$
YPRINT	$= 1 \text{ will restrict printing for node data to nodes with } y=0, \text{ and to element data to elements with one face on the } y=0 \text{ plane and an equivalent plastic strain equal to or greater than ECHECK.}$

### 3. INPUT DATA FOR THE POSTPROCESSOR

The function of the Postprocessor is to provide plots of the results in the form of state plots and time plots. The state plots show results for the entire system at a specified time and the time plots show results for a specified variable as a function of time.

It is possible to interject user comments into the data by use of a \$ character, as described for the Preprocessor.

#### a. State Plots

Input data for state plots are summarized in Figure 6. The first group of data is for geometry plots, velocity vector plots and contour plots of eight different variables. These cards should be input in order of increasing cycle numbers. This first group of cards (Geometry, Velocity, Contour) is ended with a blank card.

The second group of cards is for internal loads in a slender projectile. These should also be input in order of increasing cycle numbers and ended with a blank card.

#### Geometry Plot Card (2I5, F10.0, 2I2, 4X, 2I2, 18X, A30) -

1	= Code to specify geometry plot.
CYCLE	= Cycle number of the plot which is desired. The cycle numbers of the data written on the restart tape are given in the printed output of the Preprocessor and the Main Routine. If <b>CYCLE</b> = 0, the plots are requested on the basis of time.

TIME	= Time of the plot which is desired. Plots can be requested by either TIME or CYCLE.
AXES	= { 0 will use the axes from the previous plot. This option allows deformed geometry to be plotted together with contours or velocity vectors, for instance. The previous VIEW is used. 1 will automatically compute the axes to include all nodes. The vertical axis is specified to be 10 units, and the horizontal axis is 13 units, using the same scale as the vertical axis. When VIEW = 5, 6, 7, then the median of the Y, X, Z span is used for the cutting plane. 2 will read the coordinate limits of the plot.
VIEW	= A code to specify the view requested. VIEW = 1, 2, 3 requests two dimensional plots of the x-z, y-z and x-y axes respectively. VIEW = 4 requests a three-dimensional plot. VIEW = 5, 6, 7 requests cutting plane plots with the cutting plane parallel to the x-z, y-z, and x-y planes respectively. VIEW = 8 requests a cutting plane plot using an arbitrarily positioned cutting plane.
FAIL	= 1 will place an "x" at the center of each fractured (partially failed) element face for VIEW = 1, 2, 3, only. Otherwise leave blank.
MATL	= { 0 will draw all materials. N will draw only elements with material number N.
TITLE	= A title which is printed on the plot.

**Plot Limits Card for AXES = 2 (6F10.0)** – This card specifies the portion of the problem which is plotted. Regions beyond those specified are not plotted. For the two-dimensional plots, the vertical axis is 10 inches long, and the horizontal axis is as specified. The length of the horizontal axis will vary since it has the same scale as the vertical axis. The vertical axes are the z axis (VIEW = 1 and 2) and the y axis (VIEW = 3). For the three-dimensional plots, the axes are scaled such that the entire region is included within the 10-inch vertical axis and a 13-inch horizontal axis.

XMAX	= The maximum x coordinate included in the plot (length) When VIEW = 6, XMAX is the position of the cutting plane.
XMIN	= The minimum x coordinate included in the plot
YMAX	= The maximum y coordinate included in the plot When VIEW = 5, YMAX is the position of the cutting plane.
YMIN	= The minimum y coordinate included in the plot
ZMAX	= The maximum z coordinate included in the plot When VIEW = 7, ZMAX is the position of the cutting plane.

- ZMIN** = The minimum z coordinate included in the plot.
- LMAX** = The maximum element number included in the plot. If both LMAX and LMIN are blank or zero, then all elements are plotted.
- LMIN** = The minimum element number included in the plot.

**3D Perspective Card for VIEW = 4 or 8 (6F10.0, 15)** – This card is included only for the 3D plots and arbitrarily oriented cutting plane plots.

**XEYE, YEYE** = Coordinates of the observer (length).  
**ZEYE**

**XPLANE, YPLANE, ZPLANE** = Coordinates included in the plane on which the results are plotted for VIEW = 4. The plane is normal to a line from XEYE, YEYE, ZEYE to XPLANE, YPLANE, ZPLANE. For VIEW = 8, this plane is the cutting plane.

**LHIDE** = { 0 will plot all free surfaces (no hidden lines)  
 1 will plot only surfaces which are visible to the observer. This option can require significant CPU time, especially if the nodes are not memory contained.  
 2 will produce two plots, one each with LHIDE = 0 and LHIDE = 1.  
 LHIDE is not used for VIEW = 8.

**Velocity Vector Plot Card (6I5, F10.0, 5A6)** – Only previously undefined variables are defined. See Geometry Plot Card description for others. Cutting planes, VIEW = 5, 6, 7, or 8, are not implemented for velocity plots.

- 2** = Code to specify velocity vector plot.
- EDGE** = { 0 will draw all element faces.  
 1 will plot only an outline around the external surfaces for VIEW = 1, 2, 3. Otherwise leave blank.
- ARROW** = 1 will place arrowheads on the velocity vectors.
- VSCALE** = The velocity that will give a velocity vector with a length of 1.0 using the scale of the plot. If left blank, VSCALE will be determined to give the longest vector a length of two percent of the length of the vertical axis.

**Plot Limits Card for AXES = 2 (6F10.0)** – This is the same as described for Geometry Plots.

**3D Perspective Card for VIEW = 4 (6F10.0)** – This is the same as described for Geometry Plots except hidden line option is not allowed



**Contour Plot Card (6I5, 10X, 5A6, 2I5)** – This card requests contour plots of element variables. Contours are determined by first computing the variable quantities at the nodes (i.e., the nodal pressure is the average of the pressures of all elements which contain the node). Then the contours are drawn through the nodal quantities. The card is mostly used for two-dimensional plots, (VIEW = 1, 2, 3). The 3D plots have the contours drawn only on the element faces. Only previously undefined variables are defined. See Geometry and Velocity Plot Cards for others. Cutting planes, VIEW = 5, 6, 7, or 8, are not implemented.

- TYPE = A code to specify which variable is requested. See Figure 6 for description of variables.
- NLINE = Number of contours to be plotted. Currently limited to 8. If NLINE = 0, six contours will be plotted at values of 5, 20, 40, 60, 80 and 95 percent of the range between the minimum and maximum variable quantity limits.
- SYMBOL = Increment at which symbols are placed on contour lines. SYMBOL = 1 will place symbols at the forward end of each contour line within an element, and SYMBOL = 5 will place symbols at the forward end of every fifth element, etc. SYMBOL = 0 will not put any symbols on the contour lines.
- PRINT = 1 will print the nodal quantities of the specified variable. Otherwise leave blank.

**Plot Limits Card for AXES = 2 (6F10.0)** – This is the same as specified for the Geometry Plot Card.

**Contour Specification Card (8F10.0)** – This card is required only for NLINE > 0.

- VAR(I) = Magnitude of contours to be plotted (I = 1, NLINE).

**Internal Loads Plot Card (I5, 5X, 2I5, 2X, 3I1, 15X, 5A6)** – This card requests plots of internal loads. The data must have been previously generated in a Main Routine run by setting LOAD = 1 on the Plot Card. Sign conventions for the internal loads are given in Figure 20. The loads are only for one-half the rod since a plane of symmetry is used in the geometry generators.

- 15 = Code which specifies internal loads plots.
- CYCLE = The cycle number of the plot which is desired. The cycle numbers of the data written on the plot tape are given in the printed output of the Main Routine. If CYCLE = 0, the plots are requested on the basis of time.
- TIME = Time of plot which is desired. Plots can be requested by either TIME or CYCLE.

AXES	=	<div style="display: inline-block; vertical-align: middle;"> <div style="font-size: 2em; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;"> 1 will automatically scale axes to include all extreme data points.  2 will allow coordinate axes limits to be specified. </div> </div>
IP	=	1 will give plots of axial loads. Otherwise leave blank.
IV	=	1 will give plot of shear loads.
IM	=	1 will give plot of bending moments.
TITLE	=	A title which will be written on the plot.

**Plot Limits Card for AXES = 2 (7F10.0) -**

PMAX	=	Maximum coordinate of vertical axial load axis (force).
PMIN	=	Minimum coordinate of vertical axial load axis.
VMAX	=	Maximum coordinate of vertical shear load axis (force).
VMIN	=	Minimum coordinate of vertical shear load axis.
BMAX	=	Maximum coordinate of vertical bending moment axis (force-distance).
BMIM	=	Minimum coordinate of vertical bending moment axis.
LENGTH	=	Maximum coordinate of horizontal axis, which is defined as the deformed centerline distance from the free end of the rod (length).

**b. Time Plots**

Input data for time plots are summarized in Figure 7. System Plot Cards should be input first, followed by the Internal Loads, Individual Node and Individual Element Plot Cards. The variables are plotted as a function of time. The plot axes are divided into ten units each. End with a blank card.

**System Plot Cards (2I5, 5X, F5.0, 4F10.0, A20) -** These cards request plots of the system variables. Each plot contains data for the projectile, the target and the total system (projectile plus target). These data must have been previously written on the plot tape by setting SYS = 1 on the Plot Card in the main Routine.

TYPE	=	A code describing the type of plot. See Figure 7 for description of type. It must be in range of 1-26.
AXES	=	<div style="display: inline-block; vertical-align: middle;"> <div style="font-size: 2em; vertical-align: middle;">{</div> <div style="display: inline-block; vertical-align: middle;"> 0 will automatically select coordinates to include maximum and minimum values of variable for total duration of time.  1 will read the coordinate limits of the plot. </div> </div>
SCALE	=	Factor by which the variables are multiplied before plotting.

**TMAX** = Maximum time included on horizontal axis if AXES = 1 (time).  
**TMIN** = Minimum time included on horizontal axis if AXES = 1 (time).  
**VMAX** = Maximum variable included in vertical axis if AXES = 1.  
**VMIN** = Minimum variable included on vertical axis if AXES = 1.  
**TITLE** = A title written on the plot.

**Internal Loads Plot Cards (3I5, F5.0, 4F10.0, A20)** – These cards request plots of internal loads at a specified location in the slender projectile. These data must have been previously written on the plot tape by setting LOAD = 1 on the plot card in the Main Routine. Only previously undefined variables are defined. See System Plot Cards description for others.

**TYPE** =  $\left\{ \begin{array}{l} 27 \text{ will plot axial loads.} \\ 28 \text{ will plot shear loads.} \\ 29 \text{ will plot bending moments.} \end{array} \right.$   
**LAYER** = The layer of elements at which the loads are plotted. Layer I is mid-way between node planes I-1 and I where node plane 1 is at the free end of the projectile.

**Individual Node Plot Cards (3I5, F5.0, 4F10.0, A20)** – These cards request plots of nodal variables. These data must have been previously written on the plot tape by specifying the requested nodes on the Designated Nodes Card in the Main Routine. Only previously undefined variables are defined.

**TYPE** = A code describing the type of plot. See Figure 7 for description of types. It must be in the range of 30-39. Note that acceleration data (TYPE = 36-38) may be incorrect for sliding surface and rigid body nodes.

**NODE** = Specific node for which plot data are requested.

**Individual Element Plot Cards (3I5, F5.0, 4F10.0, 3A6)** – These cards request plots of element variables. These data must have been previously written on the plot tape by specifying the requested elements on the Designated Elements Cards in the Main Routine. Only previously undefined variables are defined.

**TYPE** = A code describing the type of plot. See Figure 7 for description of types. It must be in the range of 40-53.

**ELE** = The specified element for which plot data are requested.

#### 4. PROGRAM STRUCTURE AND FILE DESIGNATION

EPIC-3 consists of four FORTRAN-77 programs, PREP, MAIN, POST1, and POST2. The Preprocessor, PREP, converts the information given in the input data into the form used in a restart file and writes a restart file. The Main Routine, MAIN, reads a restart file, advances the simulation for some time cycles, and writes both a new restart file and plot files at user requested simulation times. The Main Routine can read any restart file (PREP or MAIN), which allows the simulations to be carried out in several smaller runs or one larger run. The Postprocessor for state plots, POST1, produces plots which show the state of the simulation at a given simulation time. POST1 can read restart files to produce geometry, velocity vector, and contour plots. POST1 can also read the plot data file to produce internal loads plots. The Postprocessor for time plots, POST2, produces plots which show how simulated quantities change during the simulation time. POST2 reads the plot data file. The user must request MAIN to write the proper data into the plot data file so that POST2 will have the appropriate data available. The hierarchy charts for the four programs are given in Figures 21-24 and subroutine groupings are given in Tables 1 and 2. Additional background on program structure is given in References 2 and 9.

All the files used by EPIC-3 are defined in COMMON/FILES/ except for two scratch files used by POST1. The common block is assigned values by assignment statements at the beginning of each program. The current designation and descriptions are:

IN	= 5	Input file for all programs
IOUT	= 6	Output file for all programs
ITAPIN	= 9	Restart file input read by MAIN and POST1
ITAPOT	= 10	Restart file output written by PREP and MAIN
NFILER	= 1	} Node Scratch file pair used for out of memory problems by PREP, MAIN, POST1
NFILEW	= 2	
LFILER	= 3	} Element scratch file pair used for out of memory problems by PREP, MAIN, POST 1
LFILER	= 4	
ISFILR	= 8	Sliding surface scratch file used by PREP, MAIN, POST1
ISFILW	= 14	Sliding surface scratch file used by MAIN
ITAPLT	= 7	Plot data file written by MAIN and read by POST1 and POST2
IPLTIN	= 13	Plot data file read by MAIN
ITGAD	= 11	Target addition scratch file used by MAIN

Files 1, 2, 3, 4, 8, 11, and 14 are opened as FORTRAN-77 nameless scratch files when needed.

The unit 1 is also used by PREP and MAIN. The input file on channel IN is stripped of comments and written to file TEMP.DAT on channel 1. Then TEMP. DAT is used for input on channel IN. TEMP. DAT is deleted on normal program completion.

POST1 uses two additional scratch files.

TABLE 1. SUBROUTINE GROUPINGS FOR EPIC-3 CODE

PREP	MAIN1	MAIN2	GEN	NABOR	POST1	SUBS	POST2
PREP	MAIN	MATCH	BRICK	CRUSH3	POST1	CPCLCK	POST2
GEOM	ASTRES	MIEGRU	ECORE	INVAQ	ARROW	ERAFLG	EPLT
MATL	CHANGE	MOTION	EGEOM	MEGRU3	AUTOS	EREAD	ILPLOT
MATLIB	CRUSH	MOVE	ENOSE	NABOR3	CTOUR	EREAD1	NPLOT
START	DAMAGE	MSERA	ENPLAT	SEARCH	CVALUS	EREAD2	PDATA
	EGET	MSTEST	EPLATE	STRES3	DATSET	ERTAPE	READTP
	ELOOP	MTMP2	EROD		EDGE	EWRITE	SYPLT
	EPLT	NLOOP	ESPHER		GEOM2	EWTAPE	
	EPUT	NPLOTS	MASS		GEOM3	HDATA	
	EQSTS	ORIENT	MSFLAG		GETCON	LBPOS	
	ERODE	PAVE	NBCORE		GPLOT	LPOS	
	EULER	PCALL	NBLIN		HCHECK	MSNEW	
	FIND	PREAD	NCORE		HIDEL	NBPOS	
	FORCE	REPORT	NGEOM		ILOADS	NFIX	
	FSGRAD	RIGID	NLINE		LOADP	NPOS	
	GCON	ROTOF	NNBRIK		PLINE	NREAD	
	HEBURN	SEEK	NNOSE		PRTCON	NREAD1	
	ISTRES	SLIDE	NNPLAT		SETORG	NREAD2	
	LOAD	STHARD	NPLATE		(PERSPC)	NRTAPE	
		STRAIN	NROD		SETUP	NWRITE	
		STRESS	NSPHER		SORT2	NWTAPE	
		SYMINV	RGEOM		SORT3	RECALL	
		SYMQR	SCYLN		VPLOT	SAVE	
		TARGAD	SDISK			SDATA	
		TCHECK	SGEOM			SETFLG	
		TRNST	SIZE			SWITCH	
		VOLUME	SLAVEN				
			SNNEW				
			SNOSE				
			SPLATE				
			SSEK2				
			TETRA				
			WEDGE1				
			WEDGE2				
			WRITEG				

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TABLE 2. REQUIRED GROUPS OF SUBROUTINES FOR VARIOUS TYPES OF RUNS

TYPE OF RUN	REQUIRED SOUBROUTINE GROUPS							
	PREP	MAIN1	MAIN2	GEN	NABOR	POST1	SUBS	POST2
PREPROCESSOR	X			X			X	
MAIN ROUTINE (NO NABOR NODES)		X	X	X			X	
MAIN ROUTINE (WITH NABOR NODES)		X	X	X	X		X	
STATE PLOTS						X	X	
TIME PLOTS								X

IFILE1	= 11	} Used for EDGE option on velocity and contour plots
IFILE2	= 12	
ITRAIN	= 11	} Used for three dimensional perspective plots
ITEMP	= 12	

## 5. OPTIONS FOR MEMORY CONTAINMENT OF DATA

EPIC-3 can simulate problems that are represented by a number of nodes and elements small enough to fit into the node and element arrays. But EPIC-3 can also simulate problems whose representation exceed the capacity of the arrays. This capability is achieved by using a primitive paging scheme. Pages of nodes or elements can be shuffled between arrays and files. The price of using this large problem capability is a slight increase in CPU time and a large amount of file access time. On a typical modern computer the file access time for out of memory elements roughly equals the CPU time. The file access time for out of memory nodes will usually be less because there usually are fewer nodes than elements. When both nodes and elements are out memory, then the file accesses are synchronized so that the file access times add together. A notable exception is in POST1 when producing hidden line geometry plots. The hidden line algorithm requires the comparison of every node with each exterior element face. A significant number of passes through the node file may be required for one picture. The most efficient way to run a simulation is with large enough array sites (nodes and elements) so that the problem is contained in memory. Even virtual memory systems are faster than the EPIC-3 out of memory option. This version of EPIC-3 has been written to allow array size changes to be made easily.

The node and element arrays in EPIC-3 are not treated as single arrays but are broken into convenient chunks called blocks. The paging scheme explained in the preceding paragraphs requires pages smaller than the array size. The page size is one block. The vectorization of element calculations imposes a block size because of the vectorization characteristic of computers and the corresponding temporary arrays which are needed. The node and element blocks can be chosen to be different sizes. In both cases (node and element) the array sizes should be a multiple of the corresponding block size.

The number of element blocks needed for array containment is printed by PREP after the element input data section. Since there is no penalty for more element blocks than needed for array containment, a series of problems can all be run with a version of MAIN large enough to contain the largest problem. PREP executes quickly so there is no big advantage to array containment of elements but it is convenient to have PREP arrays the same size as MAIN. PREP will never stop because of problems with element blocks.

Choosing the number of node blocks to use is more complex when a small node array size is desirable. The minimum number of node blocks required is printed by PREP under the heading "Bandwidth Requirements for Main Routine". If PREP does not contain this number of node blocks it will stop at that point. MAIN also requires the minimum number of node blocks.







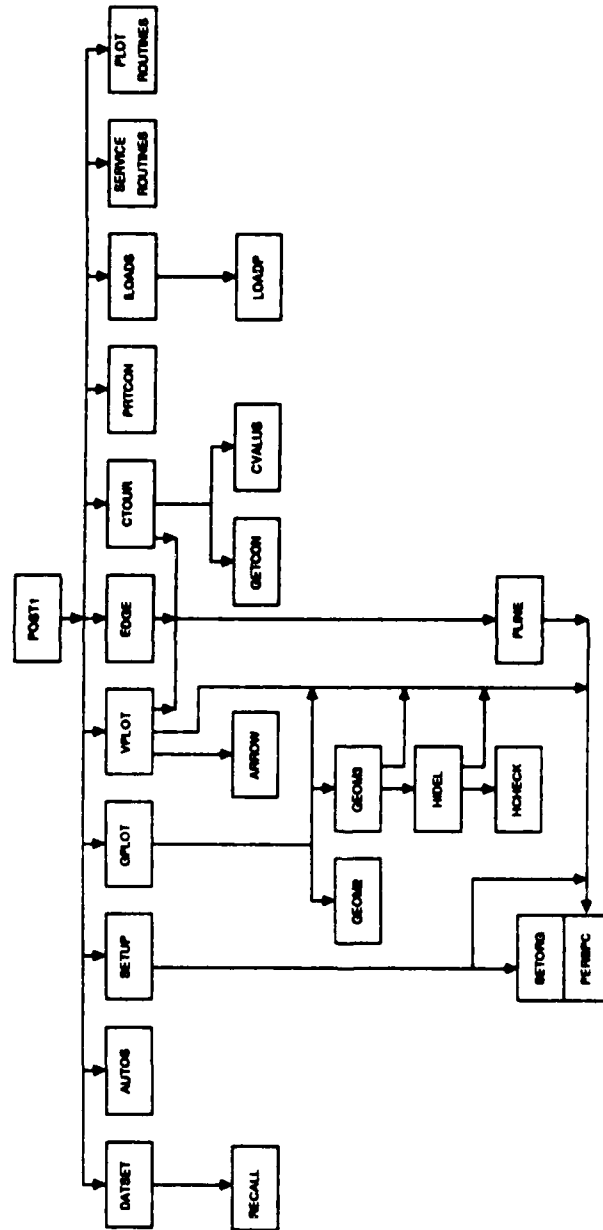


Figure 23. Hierarchy Chart for the State Plots Postprocessor

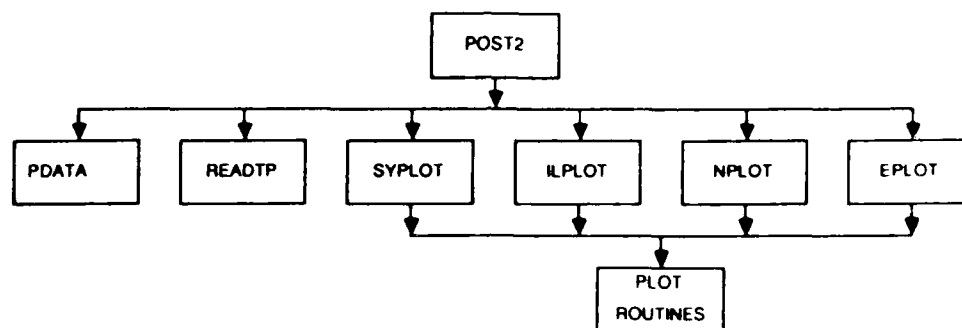


Figure 24. Hierarchy Chart for the Time Plots Postprocessor

Eroding slide surfaces pose a problem for the smallest number of node blocks required. If **NLAST**, the largest node number on an eroding master surface at any time, is known then an accurate node block number can be given. An overestimate of **NLAST** will overestimate the node block number. If **NLAST** is not known and zero given, then an underestimate of node blocks will be given by **PREP**, and **MAIN** will dynamically check as the erosion happens. When the number of node blocks needed exceeds the number available, then **MAIN** stops. There is no advantage to having more than the minimum number of node blocks until the number sufficient for array containment is reached.

## 6. INSTRUCTIONS FOR CHANGING PROGRAM DIMENSIONS

The **COMMON** declarations have been implemented in **VAX** style **INCLUDE** files. Unfortunately, this is not part of the **FORTRAN-77** standards, but every mainframe system has a similar extension. This method allows all **COMMON** declarations to be the same because they all are copies of the same file. The labeled **COMMON** block **ELEMNT** uses the **PARAMETER MAXL** to declare the size of the element arrays. The elements are handled in blocks of size **LBSIZE**. Currently **LBSIZE** is set to 60 in **PREP**. Only complete blocks can be used so a partial block at the end of arrays will be unused. The smallest declaration for all elements in memory is to set **MAXL** equal to the smallest multiple of **LBSIZE**, which is equal to or larger than the number of elements. Only **MAXL** needs to be changed to change the number of elements. After **MAXL** has been changed, all the programs except **POST2** should be recompiled and linked. Each program will automatically switch to out of memory mode when needed. The element array sizes in the various programs (**PREP**, **MAIN**, **POST1**) do not need to be coordinated, but the subroutine packages **GEN** and **SUBS** must have the same size **COMMON** blocks as the main program they are being linked to. The simplest thing to do is to use the same element array size everywhere. Similar considerations apply to nodes. The **COMMON** block is **NODE** with **PARAMETER MAXN**. The node block size is **NBSIZE**, which is set to 64 in **PREP**.

The block sizes have been chosen carefully. The CRAY 1, which can vectorize this code, had a limit of 64 elements in a quick vector loop, so this sets an upper limit on the block size. The technique for pressure averaging in bricks requires that all 6 elements be present together in a block, so element blocks must be a multiple of 6. The existing element block size of 60 is the largest multiple of 6 equal to or less than 64. The array storage used to assist the vectorizing method in element loops must be coordinated with the element block size. The PARAMETER MAXV used in COMMON/VECTOR/ must be equal to or larger than LBSIZE. The element and node block sizes, LBSIZE and NBSIZE, are set in the opening code of PREP. This is the only place they are set. They are used to define the format of the restart files, so they are included in the restart file. MAIN and POST1 read LBSIZE and NBSIZE from the restart file.

The array storage used to assist reading and writing node and element blocks must also be coordinated with block sizes. The element buffering arrays are contained in COMMON/EBUF/. The minimum array sizes needed are  $PIEB=3+(LBSIZE*6)$  and  $PREB=LBSIZE*25$ . The node buffering arrays are contained in COMMON/NBUF/. The minimum array sizes needed are  $PINB=2+NBSIZE$  and  $PRNB=NBSIZE*17$ .

## **7. EXAMPLE PROBLEM**

Preprocessor and Main Routine input data for a tungsten projectile impacting a steel target are given in Figure 25. The geometry of the computed response is shown in Figure 26 and output data are shown in Figure 27.

OBLIQUE IMPACT OF TUNGSTEN ROD ONTO STEEL PLATE

1	0	1	1	10	0	0	0	1	2	0	39	0	0
11	0	1	1	1.0	1.5								
9	0	1	1	1.0	999.								
	1.0		1.0		1.0	0.0		0.18		-45.0			
2	0	39	0		5.0	0.25		1.0					
	0.25		0.0		0.25	0.0							
3													
2	0	2	0		0.25	0.0		0.25		0.0			
	1.0		1.0		1.0								
4	1												
39	20	5	8	8	1	1.3		0.3333		1.3	0.6667		1.0
	-4.5		0.0		0.0	4.5		4.5		-0.5			
2													
2	1	38	1	11									
3													
2	1	0	586	11									
4	1												
38	19	4	616	9									
1	4	1	623	301	615	315	0	0	0	0.0	80000.0		1.5
25	13	1	39	1	3736	4232							
	0.0		0.0		0.0		0.0						
41758.0		0.0	-41758.0				0.0	0.0		0.0	0.0000001		

OBLIQUE IMPACT OF TUNGSTEN ROD ONTO STEEL PLATE

3	0	0	1	0	0	0.0	5.0E6
	1.0	1.0E-9		0.9	0.15E-3	6.0	
0.7E-4	615	615	1920	1920			
0							
0.1E-4	1000.1	0	1	1			
0.2E-4	1000.1	0	1	1			
0.3E-4	1000.1	0	1	1			
0.4E-4	1000.1	0	1	1			
0.5E-4	1000.1	0	1	1			
0.6E-4	1000.1	0	1	1			
0.7E-4	1110.1	0	1	1			
0.8E-4	1000.1	0	1	1			
0.9E-4	1000.1	0	1	1			
0.1E-3	1000.1	0	1	1			
0.11E-3	1000.1	0	1	1			
0.12E-3	1000.1	0	1	1			
0.13E-3	1000.1	0	1	1			
0.14E-3	1000.1	0	1	1			
0.1E-0	0.1	0	1	1			

Figure 25. Input Data for the Example Problem

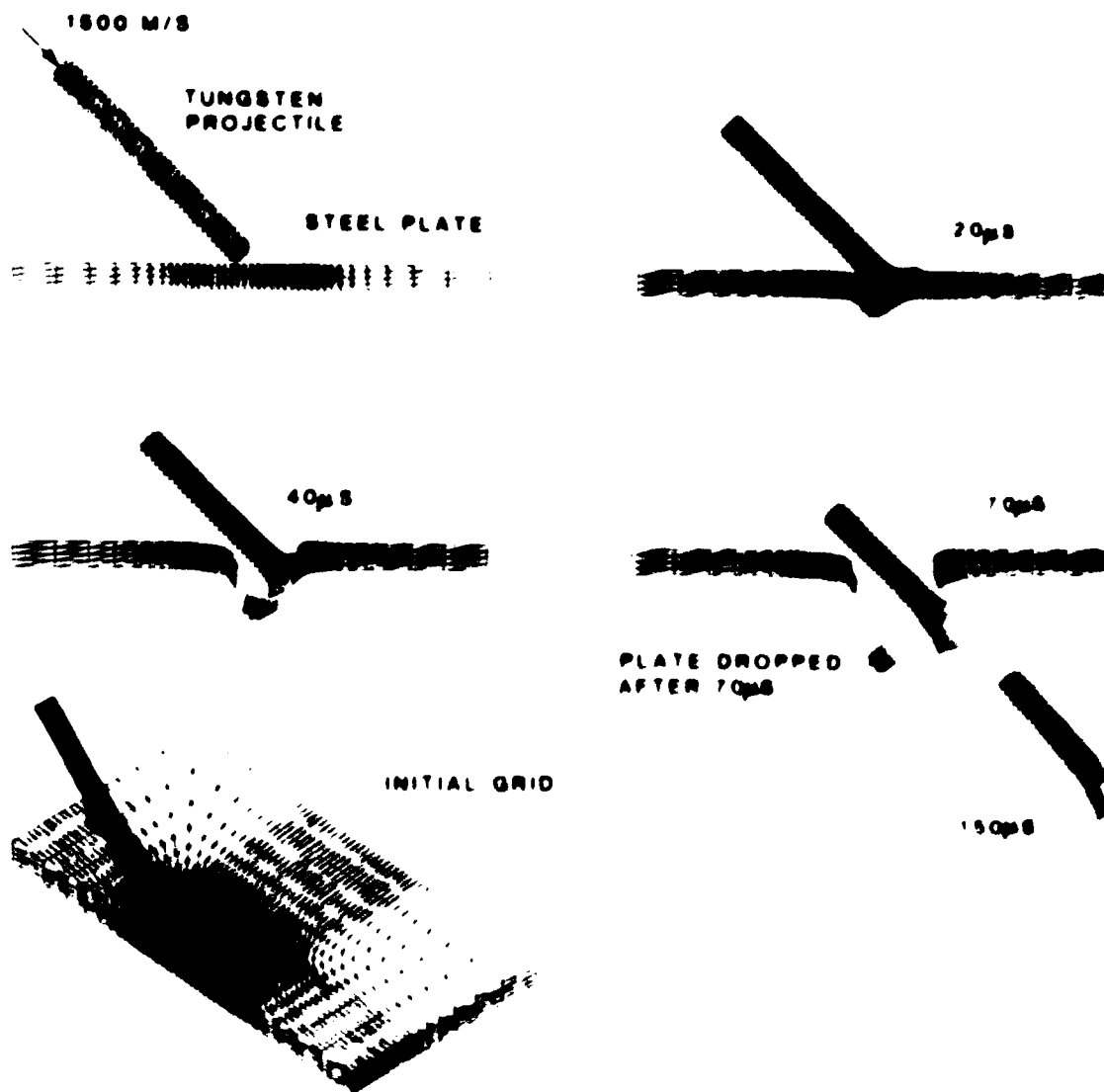


Figure 26 Computed Response of Example Problem

```

ASE NUMBER      *      1
FILE            *      1
TIME            *      0.000273E+04
TIME INCREMENT  *      0.152050E+04
P TIME HOURS    *      0.294702E+01
SYSTEM CODE ENEFF *      0.000000E+00
LOCAL CODE ILUAL *      0
TAPE CODE ISAVE *      0

```

SUMMARY OF SYSTEM DATA FOR FILE 1 AT TIME = 0.000273E+04

	PROJECTILE	TARGET	TOTAL SYSTEM
MASS	0.144432E+03	0.140730E+01	0.155494E+01
ENTERED MASS	0.144432E+03	0.140730E+01	0.155494E+01
MOMENTS OF INERTIA ABOUT X AXIS	0.538709E+03	0.160659E+01	0.299025E+01
MOMENTS OF INERTIA ABOUT Y AXIS	0.154987E+04	0.101362E+00	0.102922E+00
MOMENTS OF INERTIA ABOUT Z AXIS	0.574419E+03	0.126318E+00	0.130503E+00
TOTAL ENERGIES	0.111316E+07	0.151401E+04	0.126464E+07
POTENTIAL ENERGIES	0.154318E+00	0.196705E+05	0.199205E+05
INTERNAL ENERGIES	0.591759E+05	0.111811E+04	0.171787E+04
PLASTIC WORK	0.156397E+05	0.936277E+05	0.129267E+06
MAXIMUM X COORDINATES	0.514544E+01	0.450992E+01	0.535454E+01
MINIMUM X COORDINATES	0.928714E+00	0.450157E+01	0.450157E+01
MAXIMUM Y COORDINATES	0.308810E+01	0.450904E+01	0.450904E+01
MINIMUM Y COORDINATES	0.501451E+01	0.000000E+00	0.501451E+01
MAXIMUM Z COORDINATES	0.252756E+01	0.843248E+02	0.202756E+01
MINIMUM Z COORDINATES	0.251097E+01	0.253389E+01	0.253389E+01
MAX. VELOCITY	0.149995E+00	0.116126E+01	0.477807E+01
MIN. VELOCITY	0.131332E+00	0.275358E+01	0.215133E+01
Avg. VELOCITY	0.444212E+00	0.267746E+00	0.285795E+00
MEAN MOMENTA IN X DIRECTION	0.145240E+01	0.464224E+01	0.311689E+02
MEAN MOMENTA IN Y DIRECTION	0.456052E+00	0.108012E+01	0.624066E+01
MEAN MOMENTA IN Z DIRECTION	0.262184E+02	0.495104E+01	0.311694E+01
MEAN VELOCITIES IN X DIRECTION	0.355381E+05	0.313172E+03	0.260193E+04
MEAN VELOCITIES IN Y DIRECTION	0.470975E+03	0.728674E+02	0.400827E+02
MEAN VELOCITIES IN Z DIRECTION	0.351249E+05	0.336011E+03	0.260196E+04
NET VELOCITIES	0.499709E+05	0.463630E+03	0.283146E+04
ANG. LAP MOMENTA ABOUT X AXIS	0.535009E+00	0.981891E+01	0.629942E+01
ANG. LAP MOMENTA ABOUT Y AXIS	0.150017E+01	0.801466E+00	0.763246E+01
ANG. LAP MOMENTA ABOUT Z AXIS	0.433744E+00	0.212947E+01	0.560439E+01
ANG. LAP VELOCITIES ABOUT X AXIS	0.294832E+03	0.376695E+03	0.210666E+04
ANG. LAP VELOCITIES ABOUT Y AXIS	0.238159E+04	0.593384E+01	0.727148E+01
ANG. LAP VELOCITIES ABOUT Z AXIS	0.752480E+03	0.168580E+02	0.629466E+03

FILE 1 AND DATA WRITTEN IN FILE 10 FOR RESTART OR POST PROCESSING

Figure 27 Output Data for the Example Problem

### **SECTION III**

## **CONCLUSIONS AND RECOMMENDATIONS**

User instructions have been provided for the EPIC-3 code. This code can be used for a wide range of problems involving high-velocity impact and explosive-metal interaction.



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